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Mineral Exploration Economics: The Search For Base Metals in Australia and Canada

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MINERAL EXPLORATION ECONOMICS: THE SEARCH FOR BASE METALS IN AUSTRALIA AND CANADA

by

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FOREWORD

This paper represents research sponsored by the Centre for Resource Studies and aimed at improving the understanding of the conditions and issues facing the Canadian mineral industry, in order to assist in formulating policy decisions in industry and government. The Centre's working papers are offered for information and discussion, in an attempt to encourage feedback to the authors and additional research in mineral policy. Opinions presented are those of the author, and do not necessarily represent the views of the Centre or its sponsors.

Margot J. Wojciechowski
Centre for Resource Studies

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This paper is a product of work on the economics of mineral exploration that has been in progress since 1973 at Western Mining Corporation (WMC) in Australia, and since 1976 at the Centre for Resource Studies in Canada. We acknowledge and thank both of these organizations for their encouragement.

The study which forms the basis for this paper was completed for WMC early in 1983. We would like to express our appreciation to Ian Levy of WMC who provided research support and liaison for the project and made an important contribution to its success. We also wish to thank Michel Bilodeau, Department of Mining and Metallurgical Engineering, McGill University, for the computer modelling and analysis required for the study.

An earlier version of this paper was presented at a conference on mineral exploration economics, convened by John Tilton and Hans Lansberg at the International Institute for Applied Systems Analysis, Laxenberg, Austria, in December 1983. Papers from this meeting are being published by Resources for the Future in World Mineral Exploration: Trends and Economic Issues. We appreciate the constructive comments provided by John Tilton and an anonymous reviewer on our conference paper. We also thank Dorothy Sawicki of Resources for the Future for her excellent work in editing the manuscript. Most of her suggestions are incorporated in the present paper.

SUMMARY

Historically, Australia and Canada have displayed similar patterns of mineral exploration and development. These overall patterns suggest that the economics of base metal exploration in the two countries may also be similar. The purpose of this paper is to examine that premise and to explain, in the light of historical evidence, similarities and differences in base metal exploration between the two countries in a way that will be useful for corporate planning and the analysis of government policy.

The study assesses the economic relationship between real expenditures for base metal exploration and the potential returns from the resulting discoveries. It focuses on the modern era of base metal exploration which began in Australia during the 1950s and in Canada after World War II. The periods analyzed are 1955-78 and 1946-77 for the two countries, respectively. The economics of base metal exploration is evaluated both on a before-tax potential-value basis and on an after-tax basis. All direct costs and revenues associated with the exploration, development, and production phases of mineral supply are included.

The main conclusion of the analysis is that the economics of base metal exploration in Australia is markedly different from the Canadian experience. Overall results indicate that, while base metal exploration in Australia has been rather marginal, decidedly positive expected values have been realized in Canada. The level of base metal exploration expenditures in Canada over the study period is found to be about three times that in Australia, while the resulting number of economic discoveries assessed is more than six times greater. Thus, an economic base metal deposit in Australia typically costs twice as much and takes twice as long to find and delineate as does one in Canada. On the other hand, the economic base metal deposits discovered in Australia are found to be twice as large on average as those in Canada.

Possible reasons for the marked differences observed in discovery costs, the expected value of exploration, and the average size of deposits discovered in Australia and Canada are considered. These reduce to two possible explanations. First, there may be a fundamental difference in the base metal endowment characteristics of the two countries, with fewer, larger deposits actually occurring in Australia. Second, base metal exploration in Australia may be much more difficult and less effective than in Canada, reflecting the efficiency of geological exploration in glaciated Canadian environments as compared to the problem of detecting medium and small deposits beneath the deeply weathered near-surface zone that blankets most of Australia.

More detailed study results show that the return characteristics of base metal discoveries in the Appalachian region of Canada are comparable to those of discoveries made in similar Paleozoic rocks of eastern Australia. Furthermore, it is only in the Paleozoic environment of Australia that the weathered zone has been removed, so that in these regions in both countries base metal exploration has probably been equally effective. This evidence indicates that overall differences in exploration costs and the size of economic discoveries in the two countries are the result of more effective exploration in Canada to date. It further suggests that an undiscovered population of small and medium-size base metal deposits under the complex weathered zone covering most of Australia awaits discovery by more advanced exploration technology.

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1. INTRODUCTION

Background

The economic health of both Australia and Canada depends to a significant extent on their mining sectors. The long-term viability of the mining sector, in turn, depends to a large degree on the success of mineral exploration. And, while luck may be a short-term determinant of exploration success, the importance of the mining sector in each of these countries is too great for its long-term survival to be left to chance. Thus the importance of a greater awareness of the economic nature of mineral exploration among exploration geologists, mining company executives, and government officials responsible for mineral policy. With a better factual understanding of mineral exploration economics, decisions affecting the mining sector can be made more rationally.

The mining cycle proceeds from exploration through development to production. Investment starts at the exploration stage, when there is not only a long period of cash outflow but a high risk of total loss through failure to make an economic discovery. For investment in mineral exploration to be economically attractive, the expected value at the very beginning of the mining cycle should be positive. Also, the rate of return on the investment should be substantially greater than the current interest rate to preserve the value of the money invested and to reward the investor for the high risk being taken. This risk can be assessed as the probability of failure to make an economic discovery or, alternatively, as the level of exploration expenditure required to be confident of success.

Objective and Scope

Historically, Australia and Canada have displayed similar patterns of mineral exploration and development. These overall patterns suggest that the economics of base metal exploration in the two countries may also be similar. The purpose of this paper is to examine that premise and to explain, in the light of historical evidence, similarities and differences in base metal exploration in the two countries.

The study compares the economics of base metal exploration in Australia during the period 1955 through 1978 with a similar assessment made in Canada for the 1946 through 1977 period. The comparison is based on historical experience evaluated in the context of current outlook conditions. Mineral exploration economics is measured by the relationship

between real exploration expenditures and the value of economic deposits discovered as a result of that exploration. Changes in the economics of exploration over time reflect the effects of depletion, which include changes in the endowment characteristics of discoveries, and advances in geologic concepts and exploration technology.

The approach applied in this paper is based on the authors' confidence in the value of providing, insofar as is practically possible, a factual economic basis for mineral exploration; of assessing exploration performance in terms of conventional measures of economic value; and of studying the past as a practical guide to planning for the future.

Organization of Study

A description of the study, its major findings, and the application of results is presented in summary form.

Chapter 2 describes the economic concepts and criteria which underlie the study, setting exploration within the mineral supply process; defining exploration costs, risks, and returns; and describing expected value criteria and risk measures. The methodology applied to assess the potential value of exploration is then discussed.

The geologic setting for the study is provided in chapter 3. Australia and Canada are subdivided into several base metal environments for assessment purposes.

Chapter 4 describes the data base assembled to evaluate exploration costs and the associated returns in the two countries. The elements of this data base include total exploration expenditures, the selection of an exploration budget rate, the listing of possible economic discoveries for evaluation, general market estimates, and estimates for each of the possible economic deposits.

The potential, before-tax value of exploration in Australia and Canada is assessed in Chapter 5 for a set of base case conditions, and then for a number of variants including exploration environments, time trends, metal prices, and annual exploration budget rates. The return characteristics of economic discoveries are analyzed, and risk criteria are evaluated. Possible reasons for observed differences in the economic characteristics of base metal exploration in the two countries are examined.

Chapter 6 appraises the after-tax value of base metal exploration. The mining taxation and royalty systems existing in 1985 in Australia and Canada are imposed on the potential value assessments to evaluate the incentive for mining company investment in exploration, and the associated government revenues. Expected value criteria are assessed on an after-tax basis for base case conditions and appropriate variants.

The main conclusions of the study are presented in Chapter 7.

Several matters summarized in the text are described in greater detail in the appendices. The possible economic deposits evaluated are classified in Appendices I and II by exploration environment and by discovery date for Australia and Canada respectively. Appendices III and IV outline the 1985 Australian and Canadian taxation and royalty payment systems used to determine the after-tax value of exploration.

2. MINERAL EXPLORATION ECONOMICS

The Mineral Supply Process

The mineral supply process consists of a series of activities by which minerals are converted from unknown geologic resources to marketable commodities. As portrayed in figure 1 and described below, the major phases of activity in the process are (1) exploration, (2) development, and (3) production. The basic stimuli of this process are the physical occurrence of mineral deposits in nature and the demand for mineral commodities in the economy. A positive response from both exploration geologists and market researchers to particular geologic and market factors combine to guide the selection of environments for exploration.

Mineral exploration, the first phase of mineral supply, is a sequential, information-gathering process consisting of two stages: primary exploration and delineation. During the primary exploration stage, potentially favourable areas of land are selected within an environment of interest and then are subjected to a series of geological, geophysical, and geochemical tests. Successful primary exploration results in the discovery of one or more mineral occurrences, although at this stage the ultimate size and value of any occurrence is unknown.

The mineral occurrences discovered provide justification for delineation, the second stage of exploration, during which information is provided for estimating the size, grade, and physical characteristics of the discovery that are relevant to mineral or metal recovery. The objective of delineation is the identification of possible economic discoveries for evaluation. When the delineation stage has yielded enough information on a particular deposit, a decision is made about developing the deposit to production. If the characteristics of the delineated deposit warrant mine development, the mineral exploration phase is completed with what is perceived to be an economic mineral deposit as its end result.

Development, the second phase of the mineral supply process, establishes productive mining and mineral processing capacity. Since processing is required to upgrade the mine product to a metal concentrate that can be transported and sold, the construction of processing facilities is carried out in conjunction with mine development. A mill may be installed at the minesite, or a common processing facility may be used to treat ores from a number of mines in a region.

When a mine has been developed and related processing facilities have been constructed, the third phase - production - commences. The mining stage of production may include stripping waste for open pits, preparing

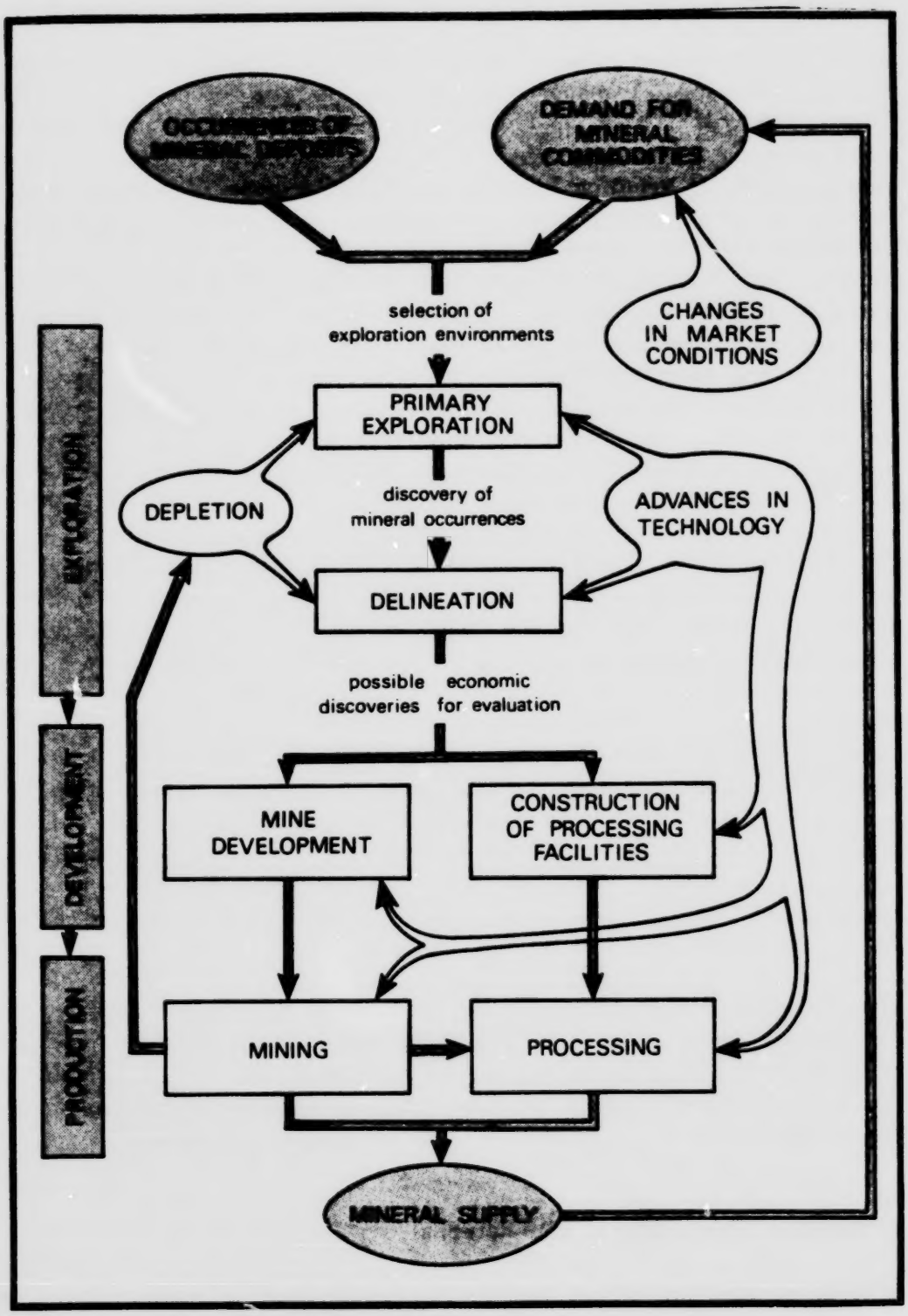

Figure 1. The Mineral Supply Process

stopes (underground excavations for mining), developing ore reserves, drilling, blasting, transporting materials to the processing facilities, filling mined-out stopes, and associated technical and planning services. For base metal operations, the processing stage of production usually includes crushing, grinding, flotation, drying, disposal of tailings, and the loading of concentrate products for shipment. Through processing, the ore produced from a mine, which might contain 2 percent copper and 5 percent zinc, may be upgraded to produce a 25-percent copper concentrate and a 55-percent zinc concentrate, with the loss of 10 percent of the copper content and 20 percent of the zinc content in the tailings.

The end result of the mineral supply process in the context of this study is the production of metal concentrate at the minesite to satisfy market demand. Market demand conditions include product transportation and smelting and refining activities as well as the sale of the metal.

The mineral supply process is dynamic in several respects. First, the market demand for mineral commodities changes with time. The factors that account for changing demand include: variations in the requirements of end uses; changes in the properties and relative costs of substitute materials; development of new product markets; and modifications in transportation, smelting, and refining conditions. Second, the physical exhaustion of mineral deposits, or depletion, is inherent in their exploitation. Thus, continual exploration is required just to sustain the existing level of mineral production. Furthermore, exploration, guided by geologic concepts and skills, is a systematic process in the long term, tending to detect first those deposits that are largest, of highest grade, closest to the surface, or closest to markets. Consequently, such deposits will, on average, be discovered, developed, and exhausted first, and deposits that are of lower grade, smaller, or harder to find come later. Thus, depletion causes the cost of mineral supply to rise over time. However, a third, offsetting dynamic force - advances in technology - is also at work. Such advances may include more efficient and extensive exploration techniques and improved mining and mineral-processing methods. Advances in technology act to reduce the cost of mineral supply. The combined effect of these market, depletion, and technological forces determines the economics of mineral supply over time.

Exploration Costs, Risks, and Returns

Mineral exploration cannot be justified as an end in itself. Thus, the economics of exploration is determined by the costs, risks, and returns of the three-phase mineral supply process described above.

Economic mineral deposits are central to the mineral supply process. Consequently, the economics of exploration can be measured by the relationship between the exploration expenditures required to find and delineate an economic deposit, and the net return associated with its subsequent development and production.

In this paper, mineral exploration economics is assessed both on a before-tax potential-value basis and on an after-tax basis. All direct costs and revenues through the exploration, development, and production phases of mineral supply are included.

Assessments of the costs, risks, and returns associated with mineral exploration are applied to measure the economic attractiveness of investment. Exploration investment criteria may be conveniently subdivided into long-term and short-term considerations. The long-term attractiveness of exploration is evaluated using various measures of expected value. The short-term problems associated with realizing expectations are assessed by risk criteria.

Expected Value Criteria

Expected value measures the average value that exploration yields in the long term, when the successes and failures associated with a very large (theoretically infinite) number of discoveries are considered. The expected value of exploration is derived from the time distribution of average cash flows for the discovery of an economic mineral deposit. This distribution is initially evaluated on a potential value basis as portrayed in figure 2. This potential value measures the productive capability of mineral resources from the viewpoint of society as a whole, and indicates what is available for sharing between industry and government prior to taxation considerations. Then, to provide measures of investment incentive from the mining company's viewpoint and government revenues, the potential value assessment is converted to an after-tax basis as depicted in figure 3. The mining company decides on an after-tax basis whether it is worthwhile to invest in exploration. Because of time value considerations, the average cash flow characteristics must be brought to a common point in time or spread evenly over a common period of time to make a valid assessment. The following two measures of expected value are applied in this study.

1. Expected Value per Economic Discovery

   An exploration expenditure E is required on average for the discovery and delineation of an economic deposit, yielding an average return R.

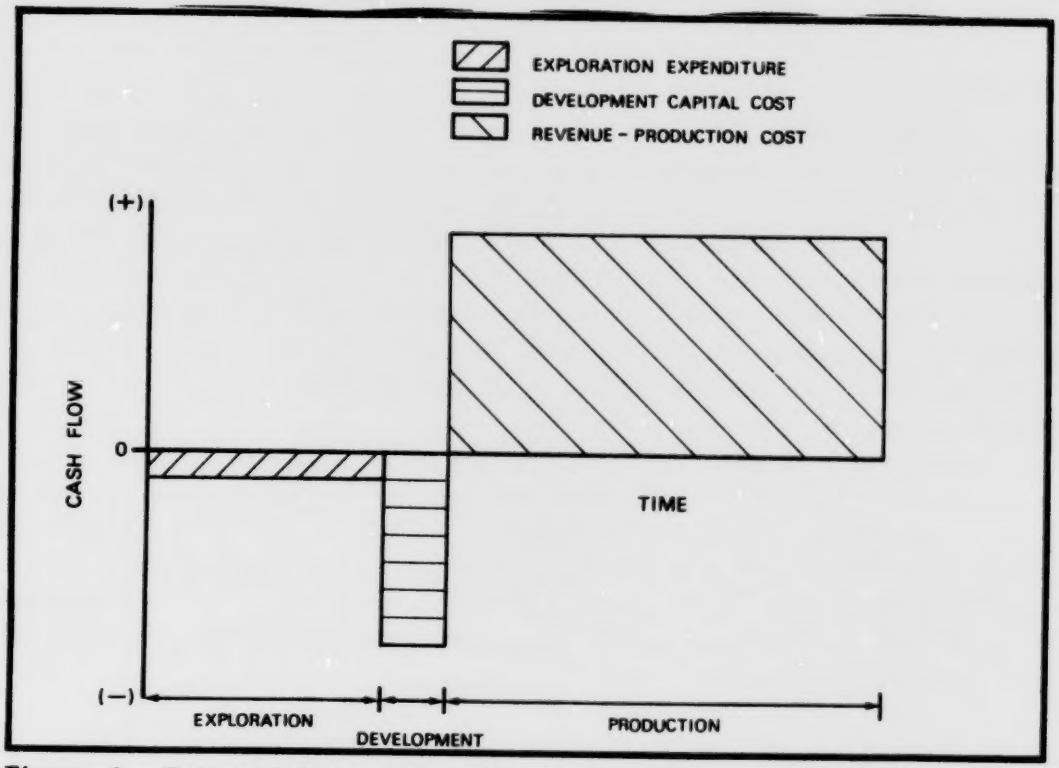

Figure 2. Potential Value Time Distribution of Average Cash Flows for an Economic Mineral Deposit

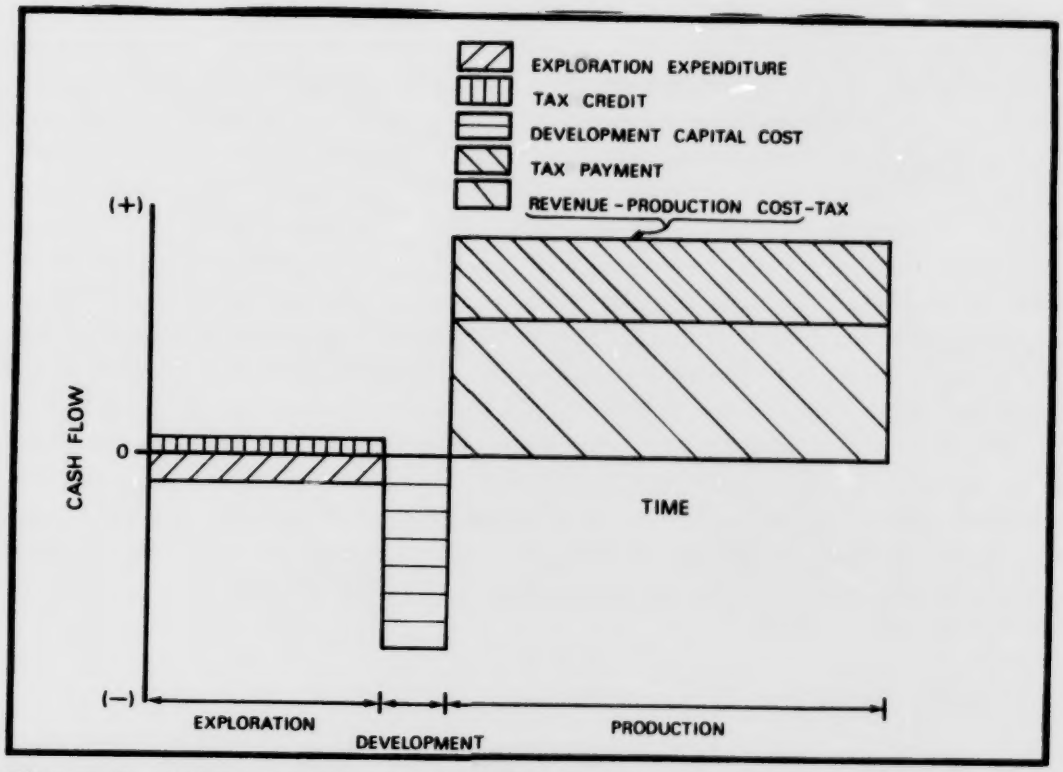

Figure 3. After-Tax Time Distribution of Average Cash Flows for an Economic Mineral Deposit

Thus:

$$EV = R - E$$

where EV = expected value per economic discovery;
R = average net return from development and production associated with the discovery of an economic mineral deposit;
E = average exploration cost required to find and delineate an economic deposit.

To make a valid comparison, R and E are expressed as discounted values at the start of the exploration phase, using a cost-of-capital estimate for investment funds as the discount rate.

The higher the EV assessment, the more attractive exploration is perceived to be in the long term. Usually an expected value per economic discovery of greater than zero is regarded as a necessary condition for investment. A negative EV signifies that exploration is an unacceptable investment in the long term, with more money going "into the ground" in discounted terms than coming out.

The expected value per economic discovery is analogous to the criterion of net present value generally used in evaluation practice. As such, this measure reflects the intrinsic economic value of mineral exploration. Thus, EV comprises both size and profitability components.

2. Expected Rate of Return

The expected discounted cash flow rate of return on investment may also be evaluated based on the time distribution of average cash flows for an economic deposit, as depicted in figures 2 and 3. By definition, rate of return is the discount rate that equates the present value of the positive cash flows with the present value of the investment. In economic terms, rate of return is the average percentage annual return that exploration is estimated to yield over the life of the mineral supply cycle. Using this method, the minimum acceptable condition for long-term exploration investment is an expected rate of return equal to the cost of capital.

Expected values are assessed in this study on the basis of overall exploration activity and reflect the average performance of all organizations that have undertaken exploration in a country or region. Obviously, there are benefits to be gained from the application of superior skills and selectivity in exploration. In exploration environments characterized

by unacceptable overall expected values, the selection of opportunities of above-average merit is a necessary condition for long-term exploration success. This can only result from the application of superior exploration skills, developed within a mining company over time through continued exposure to particular environments of interest.

Risk Considerations

Three fundamental types of risk are associated with the realization of expected values in mineral exploration. Individually and collectively, these risks present challenges to the long-term profit, survival, and growth of organizations active in exploration. They are:

1. Market risk, caused by the sensitivity of mineral exploration economics to metal price uncertainties;
2. Geologic risk, related to the uncertainty of the return, given an economic discovery, due to geologic variability among economic deposits;
3. Discovery risk, associated with the discovery of economic mineral deposits.[1]

The first type of risk is associated with the materials market for mineral commodities. There is typically a high level of uncertainty associated with the forecasting of short-term fluctuations and long-term trends in mineral market prices, including exchange rate risks. The economics of mineral exploration is highly sensitive to anticipated prices. Flexibility is required in the exploration planning process to contend with unexpected changes in market conditions, which are inevitable. Among the exploration strategies that may be adopted to address this risk is that of directing exploration toward polymetallic deposits.

The second type of risk is the variability of the return due to geologic factors, given the discovery of an economic mineral deposit. The downside risk and upside potential associated with the variability of geologic parameters among deposits have, as we will see, important implications for exploration planning.

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1. There are of course other risks. For example, the uncertainty associated with mining and processing costs may be critical when decisions concerning the development of specific mineral deposits are being taken. However, when generalizing across many deposit situations to appraise the economics of mineral exploration for countries and broad exploration environments, this type of uncertainty is not of the same magnitude as the three risks highlighted.

The third and most direct risk faced in mineral exploration is the *discovery risk: the low probability* - typically a 1 to 2 percent chance - of an economic mineral deposit, given the discovery of a mineral occurrence. The implications of discovery risk for the exploration organization should be assesssed. Because this risk is so high, the application of limited corporate funds does not ensure the realization of expected values, and exploration resources are often expended without success. The organizational risk associated with exploration success can be quantified by applying the classical problem of the gambler's ruin.[2]

The practical implication of discovery risk for a mining company is that there is a large difference between the average exploration cost required to find and delineate an economic deposit and the exploration funds required to ensure success. The relevant relationships are as follows:

$$P_1 = 1 - e^{-m}$$

where

$$m = A/E$$

thus,

$$A = - E \left[\ln (1 - P_1) \right] .$$

where P_1 = probability of discovering at least one economic deposit;
A = exploration funds available or required over appropriate planning horizon;
E = average exploration cost required to find and delineate an economic deposit;
e = 2.71828;
$\ln$ = natural logarithm.

2. The problem of the gambler's ruin in probability theory concerns a gambler with limited capital who wagers against a "house" with essentially unlimited resources. The gambler is ruined and the game terminates if at any point his or her capital balance falls to zero. For any specified set of conditions, the problem is to determine the probability that the gambler will be ruined.

For example, the exploration funds required to be 90 percent sure of making at least one economic discovery are 2.3 times the average exploration cost associated with an economic discovery.[3]

Methodology for Assessing the Potential Value of Exploration

The potential value of mineral exploration is defined as the difference between the revenues realized from mineral production and all the costs

---

3. $A = -E[\ln(1 - .90)] = -E[-2.3] = 2.3\ E.$

The large difference between the average exploration cost required to find and delineate an economic deposit (E) and the funds needed to ensure success (A), 2.3 times in this case, is solely due to the high discovery risk which characterizes mineral exploration. At the limit, if there was no discovery risk (that is, if the probability of success each time was unity), investing the average requirement (E) would give a 100-percent chance of success ($P_1 = 1.0$, and $A = E$). The formulae given indicate that the difference depends on E itself. That is because E is a function of discovery risk:

$$E = C/p$$

where C = average exploration cost associated with the discovery of a mineral occurrence;
p = probability of an economic mineral deposit given the discovery of a mineral occurrence or, in other words, discovery risk.

The relationships presented represent a Poisson approximation of the binomial distribution which is valid when p is small and n, the number of trials, is large (conditions normally fulfilled in mineral exploration). The critical importance of discovery risk (p) can perhaps be more clearly seen from the exact binomial formulation:

$$P_1 = 1 - (1 - p)^n.$$

where $n = A/C$

thus, $$A = C\left[\frac{\log\ (1 - P_1)}{\log\ (1 - p)}\right]$$

required to realize that revenue, including an allowance for the cost of capital. Since the cost of capital is deducted, this potential value represents the increase in real wealth that results from investing in exploration rather than in some other economic activity.[4] Thus, potential value reflects both the quality of mineral resource endowment and the economic viability of exploration. It also measures the productive capability of mineral resources and represents what is available for sharing between industry and government before mining taxation considerations.

The expected value and risk characteristics of mineral exploration are evaluated on the basis of historical footprints. Two assumptions are necessary if the results are used to plan for the future. First, deposits yet to be found must resemble, in economic terms, those that have been found to date. Second, the cost of making a future discovery must be similar to the cost in the past. Assessment of the cash flow characteristics associated with mineral exploration is based on actual experience over a relevant historical time period. This information is then placed in the context of current outlook conditions.

In essence, the methodology (diagrammed in figure 4) follows these steps.

1. Total exploration expenditures are estimated for the historical time period of interest.
2. Significant deposits discovered as a result of these expenditures are classified by discovery date and listed for evaluation.
3. The cash flow characteristics of the development and production phases for each of these possible economic discoveries are evaluated on the basis of current outlook conditions.
4. Discoveries that, on evaluation, satisfy minimum conditions of size and profitability are considered to be economic deposits.
5. Cash flow characteristics of the development and production phases of all economic deposits are averaged.
6. Total exploration expenditures, which can not in general be directly associated with the economic discoveries, are prorated across all economic deposits evaluated.
7. The estimate for the exploration phase is integrated with the average characteristics for the development and production phases to portray the time distribution of average costs and revenues for an economic deposit from the start of exploration to the end of production.
8. Several expected value criteria and risk measures, defined above, are derived from the assessment. These indicators reflect the potential value of mineral exploration.

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4. The cost of capital is a real cost which affects the new wealth created by mineral exploration.

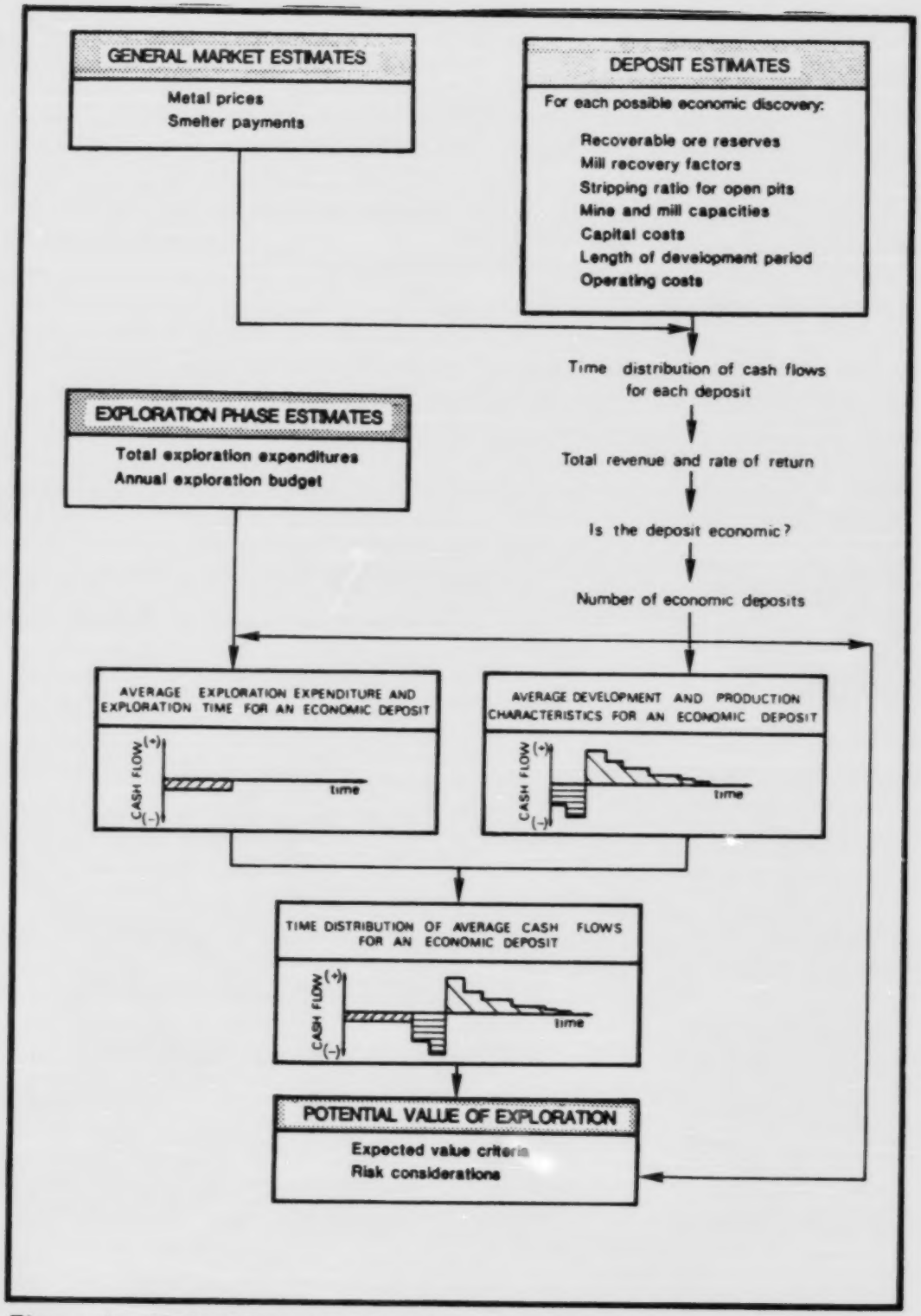

Figure 4. Methodology for Assessing the Potential Value of Exploration

More specifically, the development and production phase characteristics for each of the possible economic discoveries (step 2 above) are evaluated (step 3), as shown in figure 4, by combining general market estimates of metal prices and smelter payments with estimates for individual deposits of the following: recoverable ore reserves; mill recovery factors; a stripping ratio for open pits; mine and mill capacities; capital costs, including the working capital requirement; the length of the preproduction development period; and operating costs. These estimates, based on the actual historical record, attempt to portray how each deposit would look today if it was awaiting development. A number of measures of economic worth are derived from the resulting cash flow distributions, including the total sales revenue generated and the rate of return. Those discoveries that satisfy minimum conditions for total revenue (size) and rate of return (profitability) are deemed to be economic (step 4). The cash flow estimates for all economic deposits are then averaged (step 5), resulting in a time distribution of average cash flows for the development and production phases of the mineral supply process.

With respect to appraisal of the exploration phase (step 6), the total exploration expenditure estimate (step 1) is divided by the number of economic deposits assessed (step 4) to determine the average exploration expenditure required to find and delineate an economic deposit. To evaluate the average exploration time that would be needed to make an economic discovery, the average exploration expenditure per economic discovery is divided by an assumed most-efficient annual exploration budget rate. These estimates for the exploration phase are then integrated with the appraisals for the development and production phases.

As portrayed in figure 4, the end result of this evaluation process is an assessment of the time distribution of average cash flows for an economic deposit over the entire mineral supply process (step 7). Expected value and risk measures derived from these estimates portray the before-tax, potential value characteristics of mineral exploration.

3. GEOLOGIC SETTING AND EXPLORATION CONDITIONS

Geologic Setting

Australia and Canada can be conveniently subdivided into the base metal exploration environments shown in figures 5 and 6. The time chart presented in figure 7 compares the classification used in the two countries. The Australian subdivision is by geologic age, whereas the Canadian breakdown is primarily by region, with the regions then being classified by age. Thus, subdivisions of the exploration environment used in Australia and Canada are only partially equivalent, reflecting the independent origins of the work that provides the basis for the Australia-Canada comparison made in this paper. Also, exploration expenditure data for Canada are only available by region.

The geologic evolution and epochs of mineralization in Canada and Australia were similar for more than 3 billion years. Prior to 2.5 billion years b.p. (before the present), belts of volcanic rocks and sediments derived from these rocks accumulated in areas now recognized as Archean provinces. Base metal deposits of copper and zinc, some containing gold, silver, and lead, formed at this time in the Shield region of central Canada and in Western Australia.

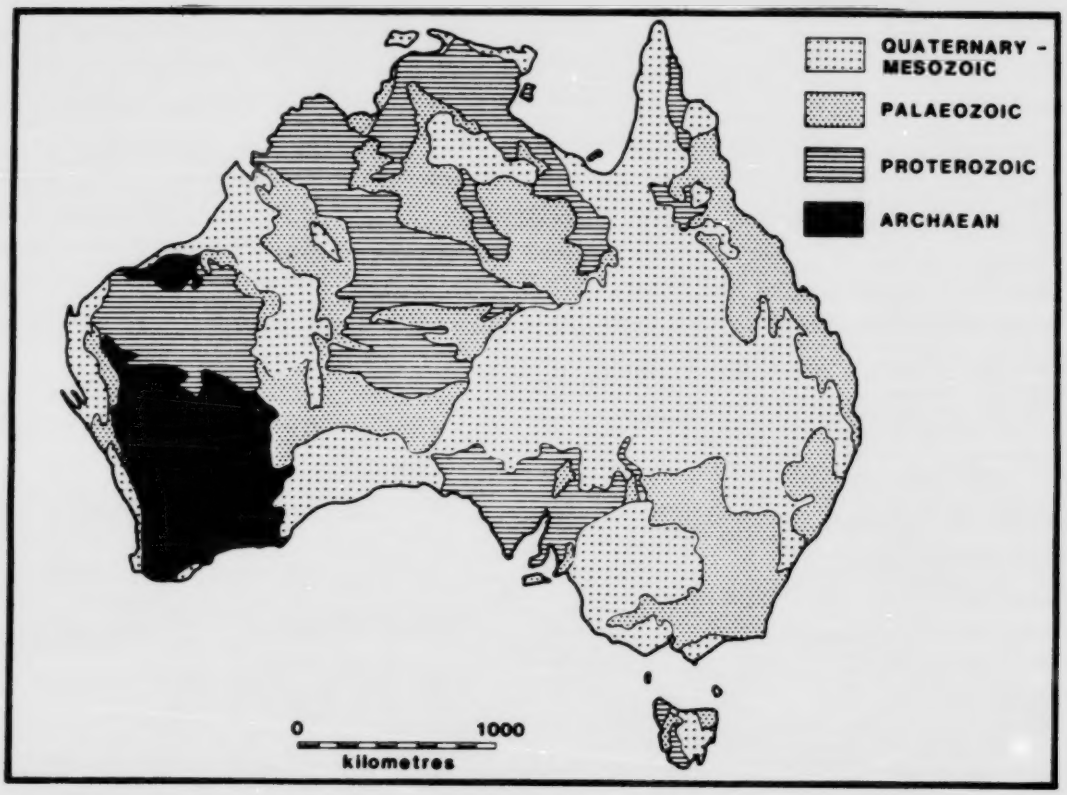

Figure 5. Geologic Map of Australia

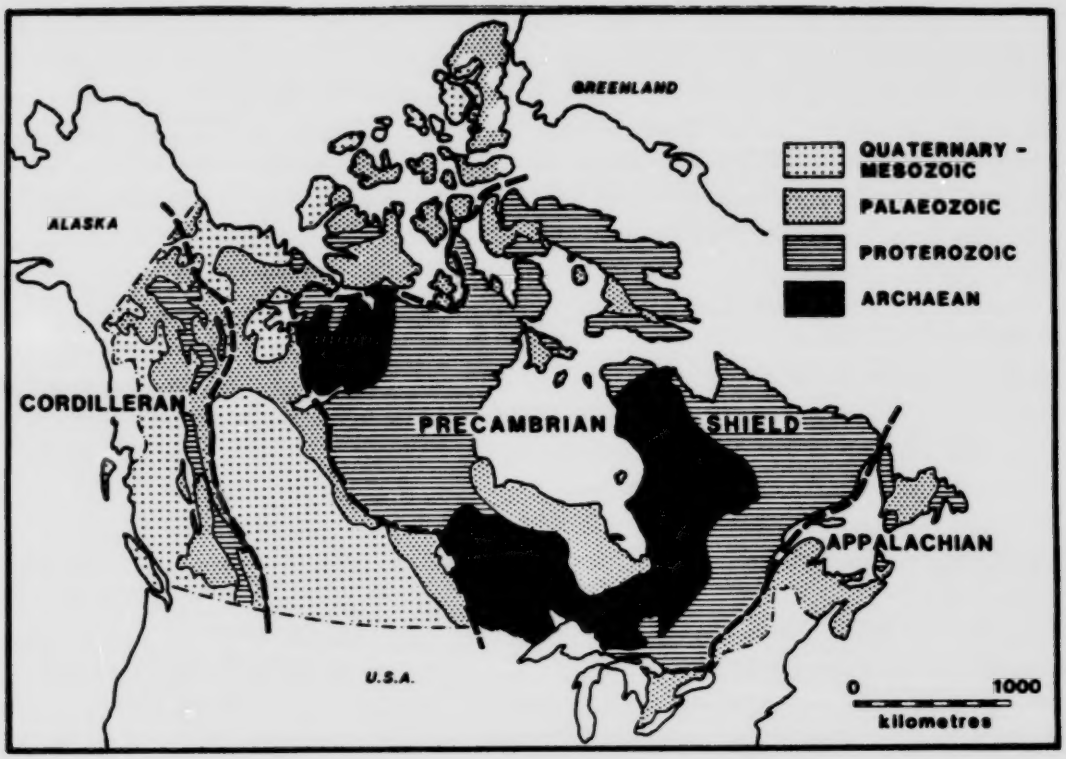

Figure 6. Geologic Map of Canada

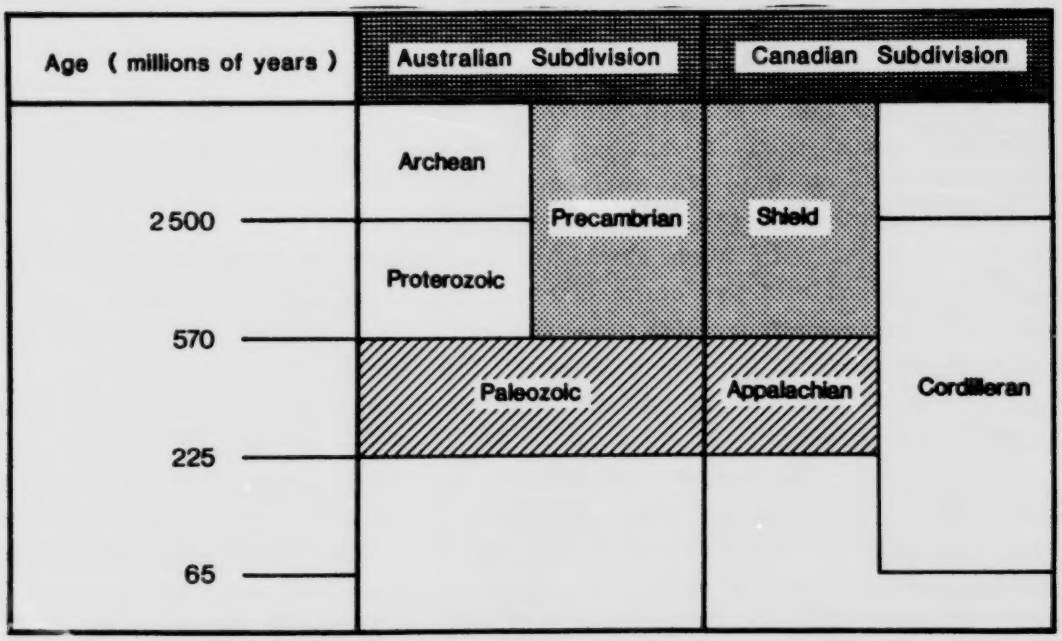

Figure 7. Base Metal Exploration Environments of Australia and Canada

The Proterozoic period, which followed the Archean era, extended from 2.5 billion years to 570 million years b.p. During the early part of this period the earth's atmosphere became oxygenated, and sediments similar to those of the present formed, along with volcanic rocks. Base metal deposits of lead and zinc formed in western Canada, while deposits of lead-zinc, lead-zinc-copper, and copper-gold formed in Australia. During the Paleozoic period (570 million to 225 million years b.p.), deposits of lead, zinc, and copper formed both in the Cordilleran and Appalachian regions of Canada (figure 6) and in rocks of the same age in eastern Australia (figure 5). Base metal mineralization continued in the sedimentary-volcanic environments of the Cordilleran region of Canada during the Mesozoic period (225 million to 65 million years b.p.) when important copper and copper-molybdenum deposits were formed.

Exploration Conditions

Mineral exploration is strongly influenced by surface and near-surface conditions. The deposits that outcrop were the first to be discovered by the relatively unsophisticated exploration of the early prospectors. But both Australia and Canada have extensive areas of concealed bedrock where the discovery of mineral deposits had to await the advent of drilling and more scientific prospecting. Use of these techniques began vigorously in Canada about 1946 and in Australia during the 1950s.

The type of bedrock concealment is very markedly different in each country. In Canada, it is largely in the form of extensive glacial debris and freshwater lakes beneath which the bedrock is essentially free of the effects of weathering. Concealed, sulfide-bearing base metal deposits can therefore exist close to the surface beneath this cover. In Australia, in contrast, extensive areas are covered with detritus and zones of highly-weathered rock. In such areas the base metal sulfides are destroyed near the surface and to depths often in excess of 100 meters and now lie beneath a near-surface zone that is difficult to penetrate with electrical geophysical prospecting techniques. The black and shaded areas in figure 8 show the extent of this weathered zone of concealment on the Australian continent.

These different surface and near-surface conditions have had a strong influence on the nature, cost, and timing of effective scientific exploration. In Canada relatively rapid and cheap airborne electromagnetic prospecting methods became available in the late 1940s and early 1950s. They were effective because they could penetrate the glacial debris over large areas. In Australia these techniques were largely ineffective. The

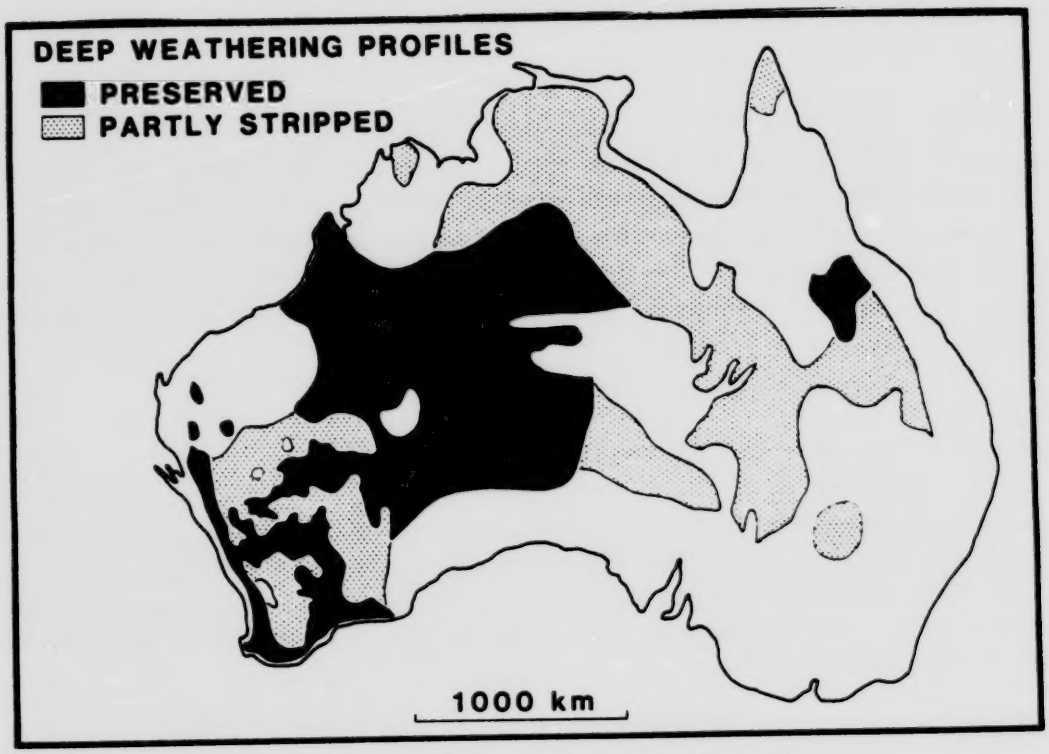

Figure 8. Weathered Zones of Concealment in Australia

near-surface debris and weathered zones in Australia have a high electrical conductivity; consequently, effective geophysical mineral prospecting with electrical systems was delayed until more sophisticated systems of geophysical exploration evolved in the 1960s and 1970s. Even today much of Australia is difficult and costly to explore with electrical geophysical methods, and geochemical exploration is also difficult in these areas.

4. EVALUATING EXPLORATION COSTS AND RETURNS

The information required to assess the economics of base metal exploration in Australia is derived from work completed for Western Mining Corporation (see Mackenzie and Bilodeau 1983, 1984). The Canadian part of the analysis uses a generally comparable data base and methodology that has been developed at the Centre for Resource Studies. (For the most up-to-date description of the Canadian data base and methodology, see Mackenzie 1985).

Terms of Reference and Assumptions

The overall assessments of base metal exploration presented in this paper are based on the twenty-four-year period 1955-78 for Australia and on the thirty-two-year period 1946-77 for Canada.[5] While the 1955-77 period could have been used in Canada to match the Australian time frame more closely, the longer period was chosen for two reasons:

- it seemed desirable to include more information in the comparison rather than less, and
- the time periods selected correspond to the modern era of exploration for concealed deposits, which began in Canada after world war II and in Australia during the 1950s.

All money values in this paper unless otherwise specified are expressed in constant 1985 Canadian dollars (C$). The exchange rate prevailing in mid-1985, 1.10 Australian dollars (A$) per Canadian dollar, is used to convert results for base metal exploration in Australia to Canadian-dollar equivalents.[6]

An economic deposit is defined here as a discovery that realizes a total revenue of at least $20 million and a rate of return of at least 8 percent. The $20 million minimum size ensures that any deposit of signi-

5. The initial year for each period is the first year for which statistics on total exploration expenditures are available for the respective countries. As of this writing, the Canadian data base does not extend beyond 1977.
6. To convert results to United States dollars, the mid-1985 exchange rate was 0.73 U.S. dollars per Canadian dollar.

ficance is included in the evaluation.[7] The 8-percent rate-of-return investment margin has been selected as the authors' best estimate of the weighted average cost of capital for mineral investment funds.[8]

Total Exploration Expenditures

Estimates of total exploration expenditures are required for each exploration environment and time interval of interest. The intention is to include all costs associated with searching for and delineating the possible economic discoveries of interest. Unsuccessful exploration expenditures of course, are part of these costs. Total exploration expenditures are difficult to estimate, mainly because government statistics are too aggregated to be directly applicable.

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7. The size of a deposit can be measured in a number of ways. Ore reserve tonnage and recoverable metal content are two indicators that neglect grades and prices on the one hand, and prices on the other. Such criteria as cash flow and net present value combine size and profitability considerations. The measure of deposit size used throughout this study is total revenue over the life of the mine (i.e., net smelter return price times recoverable metal content valued at the minesite). Total revenue provides a valid economic measure of deposit size as distinct from profitability.

8. The weighted average cost of capital in constant money terms is comprised of the costs of individual sources of funds, which can be simply grouped into two types - debt and equity.

   The cost of debt capital is an explicit interest cost, nominated in current money terms, that must be corrected for inflation. The constant money cost of debt funds is illustrated by the 3-percent average historical interest rate that has prevailed in bond markets. This real cost varies with time, especially when the general rate of inflation increases or decreases unexpectedly. To the extent that interest payments are deductible for tax purposes, as they are for corporate income tax in both Australia and Canada, the after-tax cost of debt funds must be reduced accordingly.

   The cost of equity funds is an implicit opportunity cost that can be estimated empirically. For example, Ball evaluated a cost of equity capital for Northern Mining Corporation, an Australian company primarily concerned with diamond-mining opportunties. He estimated a most-likely constant money cost of capital for the company's equity of 6.8 percent within a possible range of 5.2 to 9.9 percent. Source: "Northern Mining Corporation NL: Estimate of a Discount Rate for Valuing Equity"; Ray Ball, Australian Graduate School of Management, August 1981, unpublished.

   In summary, considering inflation and taxation effects, debt capital represents a low-cost source of funds, with constant money after-tax costs typically in the range of 1 to 3 percent. The cost of equity funds typically varies from 6 to 15 percent. The financial structure of a mining company - basically how much debt and how much equity it utilizes - is applied to cost estimates for the individual sources to assess the weighted average cost of capital. The 8-percent weighted average cost of capital assumed in this study should be viewed within this framework.

Total base metal exploration expenditures in Australia were estimated by:

- first, deriving a series of exploration expenditures for the category "other metallic minerals on non-producing leases" from published government statistics by year, and by state and territory;
- second, estimating the percentage of these exploration expenditures spent within each exploration environment by state and territory and by year.[9]

Appropriate adjustments are made to bring the exploration expenditures to a calendar-year basis and to convert current dollar statistics to constant 1985 Canadian dollars.

Estimates of total base metal exploration expenditures in Canada are derived from annual data of Statistics Canada for metallic mineral exploration expenditures by province. To derive the study estimates, it was necessary to deduct from these provincial totals the exploration expenditures for metallic minerals excluded from the analysis, particularly nickel, uranium, and gold. The estimates for provincial base metal expenditures were then grouped within the Appalachian, Shield, and Cordilleran exploration environments.[10]

Total base metal exploration expenditures in Australia and Canada are summarized in table 1 by exploration environment and by time interval. Exploration expenditures total approximately $1.4 billion in Australia and $3.7 billion in Canada for the respective study periods.

Annual Exploration Budget Rate

Based on discussions with exploration personnel and on observations of both successful and unsuccessful exploration at work, a $6.0-million annual exploration budget has been chosen as an efficient level for an exploration organization. While opinions on this subject vary and the $6.0 million figure may be criticized, there is little doubt that the most efficient budget rate lies within the range of $3.0 to $9.0 million per year.

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9. See figures 5 and 7 for the classification of Australian base metal exploration environments.
10. For a description of the method of estimation and sources of data used for base metal exploration expenditures in Canada, see appendix II, Effects of Taxation on Base Metal Mining in Canada, B.W. Mackenzie and M.L. Bilodeau, Centre for Resource Studies, Queen's University, 1979.

Table 1

TOTAL BASE METAL EXPLORATION EXPENDITURES IN AUSTRALIA AND CANADA
(millions of constant 1985 Canadian dollars)

Category	Australia		Canada	
By exploration environment:				
	Paleozoic	565	Appalachian	508
	Precambrian	833	Shield	1,787
	Archean 257		Cordilleran	1,341
	Proterozoic 576		Other	50
By time period:				
			1946-54	329
	1955-62	112	1955-62	942
	1963-70	474	1963-70	1,447
	1971-78	812	1971-77	968
Total		1,398		3,686

The $6.0-million budget is considered large enough to afford the best possible exploration skills and techniques, and small enough to encourage a high degree of motivation and organizational efficiency. Assessments are also carried out for annual exploration budgets of $3.0 million and $9.0 million.[11] Total exploration expenditures are not changed by these budget rate variants. All that is affected is the estimated average time required for an exploration organization to discover an economic deposit.

11. A group of five to eight geologists - "hunting band" size - with an annual budget of $3.0 million to $9.0 million appears to be the most efficient and effective, retaining the characteristics of an entrepreneurial organization while avoiding the weaknesses of a bureaucracy. Bailly (1977) analyzed the relationship between exploration expenditures and the number of economic deposits discovered as a function of exploration budget size, focusing on metallic mineral exploration in Canada during the 1958-73 period. His results, converted here to 1985 Canadian dollars, show that the $1.6 million to

Possible Economic Discoveries for Evaluation

In Australia, 77 base metal discoveries that could possibly satisfy the definition of "economic deposit" were selected for evaluation, and, in Canada, 291 deposits were selected. In addition to the deposits discovered during the respective time periods studied for each country, discoveries which predate these periods are also included. The Australian deposits are listed in appendix I, and the Canadian deposits in appendix II, classified by exploration environment and by discovery date.

A discovery is considered to have been made when the deposit that ultimately forms the basis for mine development was first encountered, usually by drilling. Deposits are treated individually if their discovery required essentially independent primary exploration programs. The intention is to include for both countries all known deposits of at least 200,000 tonnes that offer medium-term potential for development.

The distribution of possible economic discoveries in Australia and Canada by exploration environment and by discovery date is shown in table 2. Of the 77 base metal deposits in Australia, 39 were discovered during the 1955-78 period. In Canada, 229 of the 291 possible economic deposits were discovered during the 1946-77 period. While discoveries made prior to the start of the respective study periods cannot be in-

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$8.5 million budget range is dramatically more efficient than larger or smaller sizes.

Annual Exploration Budget	Percentage of Exploration Expenditures	Percentage of Economic Discoveries
> $8.5 million	44	15
$3.3 - 8.5 million	14	35
$1.6 - 3.3 million	13	40
< $1.6 million	29	10

If its exploration budget is too small, the exploration organization cannot mount a modern, efficient, and competitive program. At the other extreme, companies with larger budgets typically develop organizations where procedures become formalized and bureaucratic styles develop. The inefficiencies of organizations with the larger budgets are clearly shown in Bailly's results.

A dilemma arises when a mining company wishes to commit large amounts to exploration yet remain efficient. This problem can be resolved by dividing exploration activity into a number of decentralized, semi-autonomous units that are able to maintain the favourable organization characteristics with competitive budget and staff size. These units should be given broad guidelines by a central exploration group that also provides specialized, high-quality support, and the financial backing to sustain exploration activities.

Table 2

NUMBER OF POSSIBLE ECONOMIC DEPOSITS FOR EVALUATION IN AUSTRALIA AND CANADA

Category	Australia		Canada	
By exploration environment:				
	Paleozoic	34	Appalachian	39
	Precambrian	43	Shield	146
	Archean 7		Cordilleran	96
	Proterozoic 36		Other	10
By time period:				
	Pre-1955	38	Pre-1946	62
			1946-54	45
	1955-62	7	1955-62	57
	1963-70	15	1963-70	69
	1971-78	17	1971-77	58
Total		77		291

cluded in the overall analysis of exploration economics presented here, they do help provide a more complete picture of mineral endowment characteristics and the time trend of returns from economic discoveries.

General Market Estimates

General market estimates are made to evaluate the time distribution of revenues for each of the possible economic discoveries. Since metal price is both the most important and the most uncertain variable in the assessment of cash flows, cash flows are evaluated as a function of price. An expected or mean price outlook is bounded by upper- and lower-limit prices for each mineral commodity. The prices used are shown in table 3. These are long-term average price estimates, the period of which is intended to correspond to the time frame of the three-phase mineral supply process being evaluated.[12]

12. The basic U.S. dollar price estimates have been combined with exchange rate estimates to give the widest possible domestic price range. The correlation between metal prices and the exchange rate has not been considered. It would have the effect of increasing the U.S.$/A$ and U.S.$/C$ exchange rates as a function of metal prices.

Table 3

LONG-TERM PRICE VARIANTS FOR MINERAL COMMODITIES
(1985 United States dollars)

Metal	Price Basis	Price Variants		
		Lower-Limit	Expected	Upper-Limit
Bismuth	pound	3.00	4.00	6.00
Copper	pound	.80	1.00	1.25
Gold	ounce	300	400	600
Lead	pound	.20	.30	.45
Molybdenum	pound	2.50	4.50	7.00
Silver	ounce	8	12	16
Uranium	pound U_3O_8	15	25	35
Zinc	pound	.35	.50	.60
Exchange Rates	U.S.$/A$	1.00	.85	.70
	U.S.$/C$	.90	.70	.60

The assessment of costs and revenues assumes that metal concentrate is produced at each possible mine. General net smelter return conditions for copper, lead, and zinc concentrates are used to convert the forecast metal prices to a revenue estimate for the sale of concentrate at the smelter.[13] Concentrate transportation charges are then deducted to work the smelter payment back to a minesite value.

Estimates for Individual Deposits

Based on current economic and technological conditions, estimates for the following were made for each of the possible economic discoveries in Australia and Canada: recoverable ore reserves, ore capacity, preproduction

13. The net smelter conditions for copper, lead and zinc concentrates are based on the worldwide survey and analysis of approximately 200 actual smelter contracts by Lewis and Streets. See: P.J. Lewis and C.G. Streets, "An Analysis of Base-Metal Smelter Terms", in Proceedings of the Eleventh Commonwealth Mining and Metallurgical Congress, Hong Kong, 1978, Institution of Mining and Metallurgy, London. Based on discussions with marketing personnel, a number of modifications have been made to adapt the general results of Lewis and Streets to more specific Australian and Canadian conditions.

period, preproduction capital cost, the cost of major modifications, sustaining capital, operating cost, metallurgical recoveries, concentrate grades, and concentrate transportation. These deposit estimates are based on actual historical data when available. Otherwise, generalized Australian and Canadian costing relationships are applied, reflecting an order-of-magnitude level of accuracy.

With respect to processing facilities, where more than one deposit of the same type exists in a region, deposits are evaluated on the basis of the use of a common mill facility. The overall regional mill capacity is specified, as is the distance between the deposit and the mill. The deposit is allocated a proportion of the mill capital cost based on relative capacities. The distance is used to estimate a road-haulage transportation cost for the ore. Additional road construction may be specified.

Table 4 presents average mine development parameters for the base metal deposits in Australia and Canada by exploration environment. These statistics provide typical deposit profiles.

Although Australian base metal deposits have somewhat smaller ore reserves on average than those in Canada, they have higher capital cost requirements, higher grades, and total revenues that are typically almost twice as high as those of base metal deposits in Canada.[14] These distinctions between the two countries may result from differences in basic mineral endowment characteristics, the difficulty of exploration as reflected by the character of mineral deposits found to date, and economic conditions. The marked variations in revealed endowment characteristics among environments within Australia and Canada have important implications for exploration planning.

Critique of the Data Base

There are inherent limitations in the data base assembled for this study. First, possible economic deposits are classified on the basis of their discovery dates. However, the uncertain time lag between primary exploration expenditures and discovery means that exploration expenditures included in the assessment of cost characteristics for one time interval may result in discoveries being included in the following time interval. This is particularly important if it results in the exclusion of possible

14. It may be noted in table 4 that the combination of average statistics does not give the average statistics of the combination. Thus, average recoverable ore reserves times average unit revenue does not equal average total revenue. Similarly, average recoverable ore reserves divided by average annual mill capacity does not give the average productive mine life. These inequalities are caused by correlations that exist between the variables being combined.

Table 4

AVERAGE MINE DEVELOPMENT PARAMETERS FOR BASE METAL DEPOSITS IN AUSTRALIA AND CANADA BY EXPLORATION ENVIRONMENT

Country and Environment	Possible Economic Discoveries (number)	Recoverable Ore Reserves (million tonnes)	Annual Mill Capacity (thou. tonnes)	Productive Mine Life (years)	Preproduction Capital Cost ($ million)	Unit Production Costs ($/tonne)	Unit Revenue ($/tonne)	Total Revenue ($million)
Australia	77	26	1,126	12	89	47	84	1,761
Paleozoic	34	14	830	12	70	45	80	790
Precambrian	43	36	1,361	12	103	48	87	2,528
Archean	7	6	457	10	63	40	55	297
Proterozoic	36	42	1,537	12	111	49	93	2,962
Canada	291	30	1,337	13	72	61	72	909
Appalachian	39	16	698	13	55	49	85	886
Shield	146	6	349	11	44	85	85	616
Cordilleran	96	74	3,175	16	124	32	44	1,363

Notes: revenue estimates are based on expected metal prices and evaluated at the minesite; environmental breakdowns for Canada do not include "other" regions.

economic deposits from the overall time period being assessed. For this reason, several discoveries made shortly after the end of the respective Australian and Canadian study periods have been included in the evaluation.

Second, the completeness and reliability of data on individual deposits are a function of discovery date; that is, the data base for older mines is more comprehensive than that available for more recent discoveries. This is especially important with respect to estimates of ore reserves, since development and production typically proceed on the basis of partial delineation results. The objective was to include as complete an estimate as possible for the tonnage and grade characteristics of each deposit. Nevertheless, there is a tendency to undervalue cash flows, particularly for mines discovered most recently. This bias is most significant with respect to ore reserve tonnage. The problem can be eased by periodic updating and improvement of the data base.

The importance of these two limitations in the data base to overall results depends on the length of the study period and the proximity of the end of the period to the present. The twenty-four and thirty-two-year time periods chosen for this study in Australia and Canada, respectively, are considered to be of sufficient duration to minimize the effects of these limitations. Furthermore, information has been assembled several years after the end of each period.

With respect to the estimates of exploration expenditures, there is a question as to what extent "overhead" costs are included in the totals. The instructions provided by the Australian and Canadian governments in their exploration questionnaires are poorly defined in this regard. In more recent years, the intention in Australia has been to include expenditures for other activities indirectly attributable to exploration. In Canada, the intention has been to have administrative, overhead, and head office expenditures separately reported and excluded from total exploration expenditures. Nevertheless, company practices appear to vary widely with respect to allocating the overhead component of their exploration expenditures and reporting it on government questionnaires. Thus, there is scope for improving the completeness and consistency of the uncertain estimates of exploration expenditure applied in this study.

It can be argued that the use of historical exploration expenditures results in overestimating the exploration costs that would be required under today's conditions. With the increasing effectiveness of exploration, as one argument goes, a lower level of exploration expenditure would be required now to find the deposits discovered in the past. However, depletion of mineral resources is at work as well as advances in

exploration technology and, thus, the cost of finding minerals may increase or decrease with time depending on both of these dynamic forces. This study considers these effects by examining time trends within the two major periods of study. Otherwise, it assumes that the cost of making a future discovery will be similar to the cost in the past.

It is also argued by some that exploration expenditures are overestimated because they are a function of commodity prices and the perceived incentive to invest - that is, if there is less incentive to invest in exploration now than there was in the past, exploration expenditures will be correspondingly lower. While this is no doubt true, this study does not attempt to predict <u>future</u> exploration expenditure levels but instead assesses the exploration expenditure required to achieve a particular result - the discovery and delineation of an economic mineral deposit.

The historical exploration expenditures estimated for Australia from 1955 through 1978 and for Canada from 1946 through 1977 resulted in the discovery of thousands of interesting mineral occurrences and of 39 Australian and 229 Canadian deposits that qualify as possible economic discoveries. The number of discoveries that are counted as economic depends on actual, perceived, or assumed economic conditions. Would as many of what are considered possible economic discoveries here justify as much exploration today as they did historically? That question cannot be answered, first because it is not known how the perceived investment incentive of today and that of the past compare. However, we believe that differences in incentives would be modest in relation to the high levels of uncertainty inherent in exploration. A very high proportion of exploration expenditures is made for unsuccessful programs in the course of searching for possible economic deposits, the delineation of which may be influenced by the perceived incentive to invest. Therefore, we believe that the relationship between exploration expenditures and exploration results is not sensitive to the degree of change in investment incentive that occurred during the respective Australian and Canadian study periods, and that any bias in this regard would not necessarily lead to overestimation of expenditures relative to results.

Other shortcomings in the data base reflect a compromise between the ready availability of data and the research limitations imposed by time constraints. Although there is much room for improvement, we feel that the existing data base is adequate to support meaningful assessments of the economics of base metal exploration for broad government policy and corporate planning purposes.

5. POTENTIAL VALUE OF BASE METAL EXPLORATION IN AUSTRALIA AND CANADA

Base Case Results

The base case conditions to which other results are compared are as follows:

- all possible economic deposits discovered in Australia during the 1955-78 period and in Canada during the 1946-77 period;
- expected metal price conditions;
- minimum acceptable total revenue of $20 million for an economic deposit;
- minimum acceptable rate of return of 8 percent;
- annual exploration budget of $6.0 million;
- utilization of regional milling opportunities.

Under these conditions, 17 of the 39 base metal discoveries in Australia and 106 of the 229 base metal discoveries in Canada are found to be economic. The cost and revenue characteristics of the economic deposits are used to assess the time distributions of average cash flows for an economic deposit, which are presented in figure 9. Average cash flow characteristics from these distributions are compared in table 5.[15]

Based on the cash flow results shown in figure 9, further assessments of the expected value of exploration have been made and are summarized in table 6. These base case results indicate that, while base metal exploration in Australia has been marginal overall, a decidedly positive economic return has been realized from base metal exploration in Canada.[16]

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15. With reference to the time period for the production phase, the results do not mean that the average economic deposit produces for forty-three years in Australia and forty-eight years in Canada. To correctly account for time value in the assessment, the cash flows of the economic deposits in production each year are divided by (or averaged across) the total number of economic deposits. The average cash flow for an economic deposit generally declines over the production phase because the number of economic deposits remaining in production declines. Thus, forty-three years and forty-eight years are the production periods for the longest-lived economic deposits in Australia and Canada, respectively. In fact, the average productive lives for these economic deposits are similar to the average lives of twelve years in Australia and thirteen years in Canada shown in table 4 for all possible economic discoveries.
16. These base case results, as well as the results presented below for exploration environments and other variants, represent the average performance of all mining companies that have explored in Australia and Canada. There is no doubt a high degree of variability in the

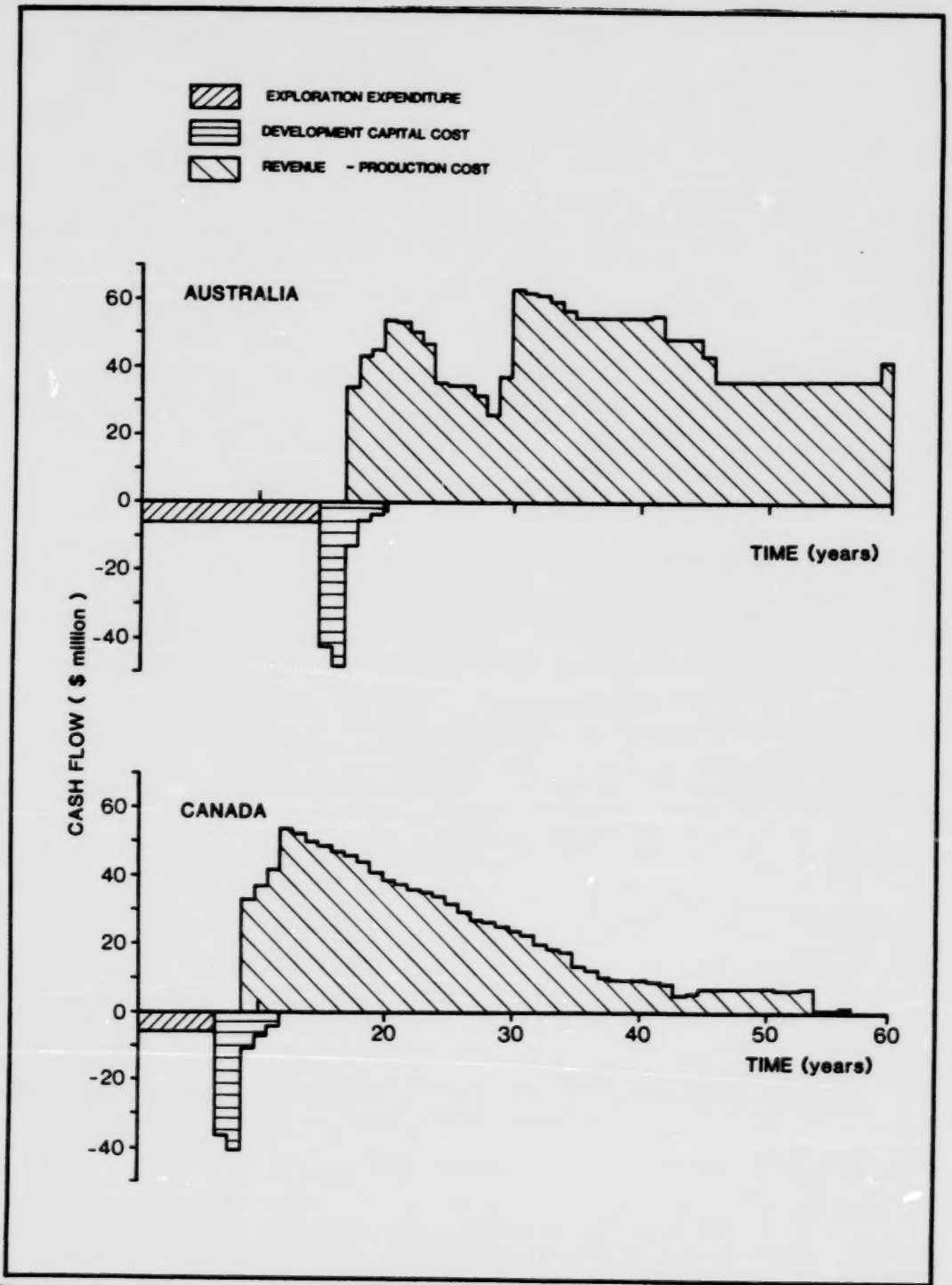

Figure 9. Potential Value Time Distributions of Average Cash Flow Characteristics for an Economic Base Metal Deposit Under Base Case Conditions

It is evident from the results presented in tables 5 and 6 that there is a large difference in the overall economics of base metal exploration in the two countries over the periods documented. The level of base metal exploration expenditures in Canada is about three times that in Australia, but the resulting number of economic discoveries has been more than six times greater. In other words, these historical footprints suggest that an economic base metal deposit in Australia costs twice as much and takes twice as long to find and delineate as one in Canada.

While base metal exploration in Australia has been more costly and time consuming than in Canada, the economic deposits that have been discovered in Australia to date are typically twice as large in terms of total revenue than Canadian economic deposits. This feature is masked in table 6 by the discounting effects associated with the long average exploration period in Australia. However, the superiority of Australian discoveries in this regard can be seen by inspecting the cash flow characteristics for the undiscounted development and production phases in figure 9 and table 5.

To permit further examination of the return characteristics of economic discoveries in Australia and Canada, table 7 presents assessments of expected value for the development and production phases only. While the profitability of base metal deposits is somewhat higher in Canada than in Australia, as shown by the results for rate-of-return, the base metal deposits discovered in Australia tend to be significantly larger, reflected in part by the results for the average return per economic deposit.[17] Does this mean that there is a fundamental difference in the size characteristics of base metal deposits in the two countries, or is it a question of the relative effectiveness of exploration technology - the efficiency of

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performance of individual companies which is masked within the average results. For example, in Australia the exploration expenditures of Western Mining Corporation (WMC) represent about 4 percent of the total included in this study. That investment resulted in the discovery of 10 percent of the possible economic deposits made by all companies. WMC's exploration performance yields a 20 percent expected rate of return as compared with the 8 percent return evaluated above for all explorers. Thus, even in marginal or uneconomic exploration environments, an acceptable economic payoff can be achieved by successful exploration organizations.

17. The difference between the rates of return for each country in tables 6 and 7 is a consequence of the exploration time and cost necessary to find and delineate an economic deposit. For example, in Australia, given an economic deposit at the start of development, the average rate of return is 36 percent. However, as viewed at the beginning of the mining cycle, prior to the start of exploration, the rate of return for the assumed conditions is only 12 percent.

Table 5

AVERAGE CASH FLOW CHARACTERISTICS FOR AN ECONOMIC BASE METAL DEPOSIT UNDER BASE CASE CONDITIONS

Characteristic	Australia	Canada
Time periods (years):		
Exploration phase	14	6
Development phase (maximum)	5	5
Production phase (maximum)	43	48
Undiscounted values ($ million):		
Revenue	3,412	1,696
Exploration expenditure	82	35
Development capital cost	113	99
Production cost	1,510	613
Cash flow	1,707	949

Table 6

ASSESSMENT OF EXPECTED VALUES FOR BASE METAL EXPLORATION IN AUSTRALIA AND CANADA UNDER BASE CASE CONDITIONS

Category	Australia	Canada
Total exploration expenditures ($ million)	1,398	3,686
Number of economic discoveries	17	106
Average exploration expenditure (E, $ million)	49	27
Average return (R, $ million)	128	188
Expected value (EV, $ million)	79	161
Rate of return (percent)	12	22

Table 7

ASSESSMENT OF EXPECTED VALUES FOR DEVELOPMENT AND PRODUCTION PHASES IN AUSTRALIA AND CANADA UNDER BASE CASE CONDITIONS

Category	Australia	Canada
Return per economic deposit ($ million)	368	294
Rate of return (percent)	36	40

Note: the expected or average return per economic deposit is assessed as a net present value at 8 percent discounted back to the start of development.

geophysical exploration in glaciated Canadian environments as compared to the problem of detecting medium and small deposits beneath the deeply weathered near-surface zone in Australia? These and other questions are addressed in the more detailed analysis of results that follows.

Exploration Environments

The assessments of expected value for the base metal environments of Australia and Canada presented in table 8 confirm the overall differences in the economics of base metal exploration in the two countries shown in table 6. There is variability in expected values among exploration environments within Australia and Canada but they are less marked than the difference which exists between the two countries.

The breakdown of the number of economic discoveries in Australia and Canada is more or less in proportion to regional exploration expenditures. Thus, the average exploration expenditure associated with the discovery of an economic deposit is in each case close to the national average.

In Australia, the Archean base metal environment gives an uneconomic overall result, signifying more money going "into the ground" in discounted terms than coming out. Results for all three Canadian base metal environments evaluated are positive and remarkably similar.

Table 8

ASSESSMENT OF EXPECTED VALUES FOR BASE METAL ENVIRONMENTS IN AUSTRALIA AND CANADA

Country and Environment	Total Exploration Expenditures ($ million)	Number of Economic Discoveries	Average Exploration Expenditure, E ($ million)	Average Return, R ($ million)	Expected Value, EV ($ million)	Rate of Return (percent)
Australia						
Paleozoic	565	9	42	84	42	12
Precambrian	833	8	55	150	95	12
Archean	257	1	72	5	-67	0
Proterozoic	576	7	49	221	172	14
Canada						
Appalachian	508	16	25	207	182	23
Shield	1,787	42	32	169	137	21
Cordilleran	1,341	38	27	193	166	20

Note: environmental breakdowns for Canada do not include "other" regions.

Time Trends

Table 9 shows time trends in the economic characteristics of base metal exploration in Australia and Canada within the respective study periods. Results reflect the combined effects of advances in exploration technology and of depletion.[18] There is evidence in both countries of some deterioration in exploration productivity with time. We reserve judgment on the significance of these trends, because past experience has shown that there is an inherent bias in the data base that tends to undervalue discoveries made most recently.

The difficulty of base metal exploration in Australia is reflected by the low rate of discovery. Seven of the twelve Australian economic discoveries since 1955 resulted from advances in exploration geochemistry - in particular, the recognition of the significance of anomalous metal values in leached, ironstone gossans. Airborne magnetic surveys were critical in several cases. These improvements in exploration technology were slow to have an effect before 1963, but since then success has been constant, if only at a very modest level. Electrical geophysics has been instrumental in discovery only since 1970, and then in only one instance. Significant advances in geologic science with respect to ore genesis began in the 1970s and together with improvements in geochemical and geophysical technology, helped to maintain the discovery rate.

In Canada, the favourable results shown in table 9 for exploration expenditures and returns for the 1946-54 period reflect the application of new exploration technology, particularly airborne electromagnetic (EM) geophysical methods, on a relatively unexplored endowment base. Airborne EM surveys, followed by drilling the highest priority conductors defined, resulted in the favourable expected values assessed. The deterioration in base metal exploration characteristics evident in the 1955-62 period suggests that depletion effects - with regard to both increasing exploration costs and diminishing returns from the resulting economic discoveries - more than outweighed any advances in technology. Specifically, the poor results probably reflect application of the 1946-54 exploration approach to lower-priority targets.

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18. These time trends do not take into account the real changes in mineral market conditions or the improvements in mining and mineral-processing technologies that have taken place during the respective study periods. Following our evaluation procedure, these factors are standardized on the basis of current outlook conditions. The intention is to isolate those facets of the economics of exploration that have resulted from the changing nature of the exploration process itself and from changes in mineral endowment characteristics as revealed through the base metal deposits discovered.

Table 9

TIME TRENDS IN ASSESSMENTS OF EXPECTED VALUE FOR BASE METAL EXPLORATION IN AUSTRALIA AND CANADA

Country and Time Interval	Total Exploration Expenditures ($ million)	Number of Economic Discoveries	Average Exploration Expenditure, E ($ million)	Average Return, R ($ million)	Expected Value, EV ($ million)	Rate of Return (percent)
Australia						
1955-62	112	3	29	351	322	22
1963-70	474	7	44	46	2	8
1971-78	812	7	58	122	64	11
Canada						
1946-54	329	21	14	281	203	29
1955-62	942	25	29	95	66	15
1963-70	1,446	33	32	259	227	24
1971-77	968	27	28	157	129	20

While the average exploration expenditure per economic discovery in Canada increased further during the 1963-70 period, as shown in table 9, the average return per economic discovery almost tripled over that of the preceding period. The application of conceptual geologic models for such purposes as area selection and the ranking of exploration targets was likely important to the improvement shown in the economics of base metal exploration. Average exploration costs declined for the most recent, 1971-77, period but this improvement has been outweighed by the notable decline in the average return associated with an economic discovery. The sharp decrease in the expected values assessed may reflect the dominance of depletion forces relative to advances in exploration technology or it may be caused by the bias in the data base that tends to undervalue recent discoveries.

Metal Price Variants

Assessments of expected value are presented in table 10 as a function of lower-limit, expected-value, and upper-limit price conditions. These results indicate the high degree of sensitivity of the economics of exploration to metal price uncertainties. As metal prices increase, there are sharp increases in the number of economic discoveries, in the average return associated with an economic discovery, and in the expected value per economic discovery and rate of return. At the same time, higher metal prices reduce the average exploration expenditure and the average time required to discover and delineate an economic deposit.[19] Thus, as indicated earlier, the uncertainty associated with metal price forecasts represents an important risk in exploration planning and government policy analysis. Flexibility is required in plans and policies to accommodate the resolution of price uncertainties with time.

As shown in table 10, differences between the Australian and Canadian results are shown to be a function of price. The expected values of base metal exploration in the two countries are unattractive and quite similar at lower-limit prices but the gap generally widens as prices are increased. The economics of Canadian base metal exploration is more responsive to price movements because of the relatively short average exploration period (see table 5).

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19. This is because more discoveries satisfy the definition of "economic deposit"; it is not due to integral change in the exploration process.

Table 10

ASSESSMENT OF EXPECTED VALUES FOR BASE METAL EXPLORATION IN AUSTRALIA AND CANADA AS A FUNCTION OF METAL PRICES

Country and Price Variant	Number of Economic Discoveries	Average Exploration Expenditure, E ($ million)	Average Return, R ($ million)	Expected Value, EV ($ million)	Rate of Return (percent)
Australia					
Lower-limit prices	6	71	3	-68	2
Expected prices	17	49	128	-79	12
Upper-limit prices	29	35	339	304	24
Canada					
Lower-limit prices	21	67	21	-46	5
Expected prices	106	27	188	161	22
Upper-limit prices	170	18	343	325	36

Variants with Respect to the Annual Exploration Budget

An annual exploration budget of $6.0 million, considered to be among the most efficient rates of expenditure (see footnote 10), is incorporated in the base case conditions. This assumption has a critical bearing on study results, particularly because at this expenditure rate fourteen years of exploration are required on average in Australia to find and delineate an economic deposit.

Assessments of the economics of exploration have also been made for annual exploration budgets of $3.0 million and $9.0 million. The consequences of these variants on the expected value measures are shown in table 11. As the annual exploration budget is increased, a significant improvement in results is apparent in both Australia and Canada. By reducing the average exploration time required for the discovery of an economic deposit, the time distribution of negative cash flows is shortened and the time distribution of positive cash flows moves toward the present. Thus, although total exploration expenditures and the number of economic deposits remain constant, the expected value measures are enhanced.

Table 11

ASSESSMENT OF EXPECTED VALUES FOR BASE METAL EXPLORATION IN AUSTRALIA AND CANADA AS A FUNCTION OF THE ANNUAL EXPLORATION BUDGET

Country and Budget Variant	Average Exploration Expenditure, E ($ million)	Average Return, R ($ million)	Expected Value, EV ($ million)	Rate of Return (percent)
Australia				
$3.0 million	33	45	12	9
$6.0 million	49	128	79	12
$9.0 million	57	182	125	14
Canada				
$3.0 million	22	120	98	18
$6.0 million	27	188	161	22
$9.0 million	29	218	189	24

Effect of the Multi-Billion Dollar Discovery

Olympic Dam in Australia and Kidd Creek in Canada are the most important base metal deposits discovered in the two countries during the respective study periods. The effect of these discoveries on the economics of exploration is examined by removing them from the assessment of expected values. Comparative results, presented in table 12, show that the two deposits - among 17 economic discoveries in Australia and 106 economic discoveries in Canada - represent a substantial part of the base metal potential in their respective countries. Their main impact is in terms of deposit size, reflected in the average return per economic discovery (R) and the expected value of exploration per economic discovery (EV). The effect of Olympic Dam and Kidd Creek on the expected rate of return of exploration, a profitability indicator, is shown to be significant but less pronounced.

If these very rare deposits did not occur, the economics of mineral exploration would be impoverished. The possibility that any exploration program can lead to one of these multi-billion dollar discoveries, although extremely improbable, is no doubt a great motivator in mineral exploration. Such a giant target likely carries weight in exploration decisions beyond its actual numerical contribution to the expected value measures illustrated here.

Return Characteristics of Economic Deposits

Potential value assessments of average return characteristics for economic deposits are summarized in table 13 subdivided by exploration environment. It should be noted that the results presented here make no allowance for exploration time and cost; the evaluation includes only the development and production phases of the mineral supply process. Discoveries made prior to 1955 in Australia and prior to 1946 in Canada are included.

Under the assumed conditions, 36 of the 77 base metal deposits discovered in Australia and 129 of the 291 base metal deposits in Canada are found to be economic, as indicated in table 13. The average profitability of economic base metal deposits in Australia, as reflected by the rate of return criterion, is shown to be somewhat higher than in Canada. This comparative result is the reverse of that previously shown for the economic discoveries made during the modern era of exploration for concealed deposits in the two countries (see table 7). Once again, however, the economic discoveries made in Australia tend to be very much

Table 12

INFLUENCE OF OLYMPIC DAM AND KIDD CREEK DISCOVERIES ON THE ASSESSMENT OF EXPECTED VALUES FOR BASE METAL EXPLORATION IN AUSTRALIA AND CANADA

Country and Deposit Variant	Number of Economic Discoveries	Average Exploration Expenditure, E ($ million)	Average Return, R ($ million)	Expected Value ($ million)	Rate of Return (percent)
Australia					
With Olympic Dam	17	49	128	79	12
Without Olympic Dam	16	51	82	31	10
Canada					
With Kidd Creek	106	27	188	161	22
Without Kidd Creek	105	27	149	122	20

Table 13

ASSESSMENT OF AVERAGE RETURN CHARACTERISTICS FOR ECONOMIC BASE METAL DEPOSITS IN AUSTRALIA AND CANADA

Country and Environment	Number of Economic Discoveries	Total Revenue ($ million)	Return ($ million)	Rate of Return (percent)
Australia	36	3,492	523	40
Paleozoic	19	1,156	224	40
Precambrian	17	6,102	858	41
Archean	1	394	132	61
Proterozoic	16	6,459	903	40
Canada	129	1,745	321	38
Appalachian	21	1,585	276	34
Shield	55	1,429	315	40
Cordilleran	43	2,417	369	31

Notes: based on expected metal prices; total revenue is evaluated at the minesite; return is assessed as a net present value at 8 percent discounted back to the start of development; environmental breakdowns for Canada do not include "other" regions.

larger[20] and the question arises as to whether this marked difference in the revealed size of base metal deposits reflects a fundamental difference in mineral endowment or results from a difference in exploration difficulty and effectiveness.

It should be noted, as shown in table 13, that the average return characteristics of base metal discoveries in the Appalachian region of Canada are comparable to those of discoveries made in what are similar Paleozoic rocks of eastern Australia. Furthermore, it is only in the Paleozoic base metal environment of Australia that the weathered zone has been removed (see figures 5 and 7), so that in these regions in both countries exploration has probably been equally effective. This clue suggests that the overall difference in the size characteristics of base metal deposits in the two countries is the result of more effective exploration in Canada to date. The discovery of small and medium-size base metal deposits under the complex weathered zone that covers most of Australia awaits appropriate advances in exploration technology.

20. Deposit size is measured here, as throughout the study, by average total revenue per economic discovery and is also incorporated, along with profitability, in the assessment of average returns per economic discovery.

One of the important risks in mineral exploration previously discussed is the variability of the return, given the discovery of an economic mineral deposit. As a consequence of the variability in tonnage, grade and other geologic characteristics among economic deposits, there is typically a wide range of possible returns distributed around the average return. To illustrate, we have examined the distribution of returns for the 36 economic base metal deposits discovered in Australia and for the 129 economic discoveries in Canada around the average returns of $523 million and $321 million, respectively, presented in table 13. Key statistics from these distributions are summarized in table 14.

Table 14

VARIABILITY OF THE RETURN FOR ECONOMIC BASE METAL DISCOVERIES IN AUSTRALIA AND CANADA: KEY STATISTICS

	Return from Economic Discoveries ($ million)	
Statistic	Australia	Canada
Upper decile	1,640	661
Upper quartile	492	295
Mean (average)	523	321
Median	78	102
Lower quartile	25	38
Lower decile	12	8

Note: returns are expressed as net present values at 8 percent discounted back to the start of development.

The variability of the return from economic discoveries in Australia is particularly pronounced, as illustrated by the 140-times difference in value between the lower-decile and upper-decile values ($12 million and $1,640 million respectively). In Canada there is also a wide range of values, with a more than 80-times difference between the lower- and upper-decile returns ($8 million and $661 million respectively).

These return distributions are also highly skewed. There are many deposits of low economic value and relatively few of very high value. Thus in Canada, for example, the mean value of economic discoveries ($321 million) is higher than the upper-quartile value ($295 million), and more than three times greater than the median or middle value of the distribution ($102 million). Given the discovery of an economic deposit in Canada, there is more than a 75 percent chance that it will yield a lower-than-average return. On the other hand, there is almost a 25 percent chance that an economic discovery will provide an above average return. There is even a small possibility of a "multi-billion dollar" discovery, the effect of which has been previously examined.

With respect to the formulation of mineral policy in government, the important message that table 14 conveys is that there is no such thing as a "typical deposit". Thus, flexibility is required in government policies to equitably and efficiently accommodate the wide range of returns inherent in mining.

Figure 10 illustrates the average mix of metal products realized from the economic base metal deposits. Thus, there is a natural market hedge associated with base metal exploration. Zinc, copper, and lead are relatively evenly balanced constituents in Australian deposits, together accounting for 72 percent of the value of production. In Canada, zinc and copper contribute 64 percent of the total revenue realized from base metal deposits, while lead contributes another 8 percent. Precious metal by-products account for 17 percent of the value of production in both countries.[21]

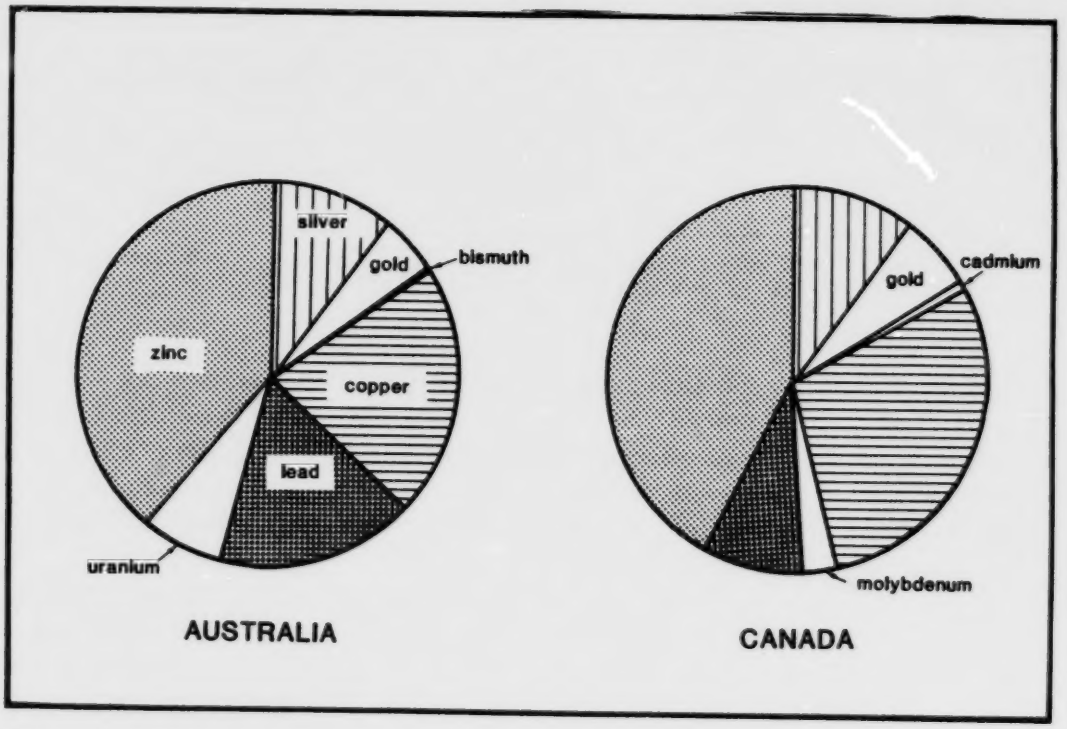

Figure 10. Mix of Metal Products from Economic Deposits in Australia and Canada

21. The metal shares depend, of course, on relative metal prices. The figures presented assume expected-value price conditions.

Comparative Endowment and Return Characteristics for Deposits Discovered Before and During the Study Periods

A previous section examined time trends in the economic characteristics of base metal exploration in Australia during the 1955-78 period and in Canada during the 1946-77 period. This section considers the complete time frame of historical experience, focusing only on the endowment and return characteristics of the mineral deposits.

Table 15 presents time trends in average endowment characteristics of possible economic deposits. Results are remarkably similar for the 38 base metal deposits discovered in Australia before 1955 and the 39 discoveries made during the 1955-78 period. In Canada the 229 base metal discoveries made during the 1946-77 period are significantly larger, on average, than the 62 deposits discovered before 1946. This difference

Table 15

TIME TRENDS IN AVERAGE MINERAL ENDOWMENT CHARACTERISTICS FOR POSSIBLE ECONOMIC DISCOVERIES IN AUSTRALIA AND CANADA

	Australian Discoveries		Canadian Discoveries	
Characteristic	Pre-1955	1955-78	Pre-1946	1946-77
Possible economic discoveries (number)	38	39	62	229
Recoverable ore reserves (t million)	24	29	14	34
Annual mill capacity (t thousand)	1,079	1,172	661	1,519
Productive mine life (years)	12	12	12	13
Development capital cost ($ million)	91	86	53	77
Unit production cost ($/t)	48	46	54	62
Unit revenue ($/t)	83	84	74	71
Total revenue ($ million)	1,921	1,605	839	928

Note: revenue estimates are based on expected metal prices and evaluated at the minesite.

primarily reflects the impact of large porphyry copper and copper-molybdenum deposits discovered during the study period.[22]

The time trends in average return characteristics of economic deposits are presented in table 16. In Australia the economic discoveries made during the 1955-78 period are of a similar size and profitability to those discovered before 1955. Economic deposits discovered in Canada during the period 1946-77 are of similar size but less profitable, on average, than discoveries made prior to 1946.[23] In this case the influence of the prophyry discoveries is more modest, because relatively few of these deposits would be economic under the current outlook conditions assumed in the evaluation.

Several possible reasons account for the apparent decline in the return per economic discovery in Australia and Canada. First, this trend may be caused by depletion; that is, the quality of deposits discovered decreases over time, as a consequence of systematic exploration. Second, advances in geologic concepts and exploration technology alter the character of discoveries, perhaps resulting in an increasing proportion of smaller or more-marginal economic deposits. Finally, changing economic conditions beyond the realm of exploration have no doubt influenced the type of exploration target sought by mining companies, contributing, for example, to the focus on porphyry deposits in western Canada in the late 1960s. It is likely that all three of these factors have played a part in determining the trends shown in table 16.

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22. Concentration on porphyry deposits came about primarily because of significant advances in large-scale open pit and mineral processing equipment coupled with positive perceptions of future copper and molybdenum markets. In Canada, tax incentives for capital expenditures also encouraged the development of porphyry deposits.

23. Note that the total revenue and return results presented in table 16 for economic discoveries in Australia during the 1955-78 period and in Canada for the 1946-77 period are the same as presented earlier for base case conditions (see tables 5 and 7). However, the results for rate of return differ. Since deposit size is incorporated in the total revenue and return measures, the indicators are in both cases weighted averages and, thus, identical. With respect to rate of return, the results shown in table 7 are derived from the time distributions of average cash flows for an economic deposit (the development and production phase estimates portrayed in figure 9) and, therefore, these, too, are weighted averages. However, the results for rate of return presented in table 16 are not weighted for deposit size; they are determined in each case by summing the rates of return for the individual economic discoveries and dividing this total by the number of economic deposits.

Table 16

TIME TRENDS IN AVERAGE RETURN CHARACTERISTICS FOR ECONOMIC DISCOVERIES IN AUSTRALIA AND CANADA

	Australian Discoveries		Canadian Discoveries	
Characteristic	Pre-1955	1955-78	Pre-1946	1946-77
Economic discoveries (number)	19	17	23	106
Total revenue ($ million)	3,564	3,412	1,971	1,696
Return ($ million)	662	368	445	294
Rate of return (percent)	39	41	45	36

Notes: revenue estimates are based on expected metal prices and evaluated at the minesite; return is assessed as a net present value at 8 percent discounted back to the start of development.

Organizational Consequences of Discovery Risk

There is a very small chance of success each time an investment is made in primary exploration. The high risk associated with the discovery of an economic mineral deposit has important consequences for the exploration organization. Even when the expected value of exploration is positive, funds are often expended without success. The important practical implication of discovery risk is the difference between the average exploration expenditure required to find and delineate an economic deposit and the exploration funds required to ensure success.

To illustrate the organizational consequences of discovery risk, assessments are made of the exploration funds required to be 90 percent sure of making at least one economic discovery. This evaluation of funding requirements is applied to the overall Australian and Canadian experiences in base metal exploration during the 1955-78 and 1946-77 study periods, and is also made as a function of exploration environments. Results are presented in table 17.

For typical Australian conditions, exploration funding of $189 million would be required to ensure success while $80 million would be necessary in Canada. These funding levels to ensure success compare with average exploration expenditure requirements per economic discovery of $82 million and $35 million respectively.

Table 17

EXPLORATION EXPENDITURES REQUIRED FOR THE DISCOVERY OF AN ECONOMIC BASE METAL DEPOSIT IN AUSTRALIA AND CANADA

Country and Environment	Total Exploration Expenditures ($ million)	Number of Economic Deposits	Average Exploration Funds Required[a] ($ million)	Exploration Funds Required To Ensure Success[b] ($ million)
Australia	1,398	17	82	189
Paleozoic	565	9	63	144
Precambrian	833	8	104	239
Archean	257	1	257	591
Proterozoic	576	7	82	189
Canada	3,686	106	35	80
Appalachian	508	16	32	73
Shield	1,787	42	43	98
Cordilleran	1,341	38	35	81

[a]: The exploration expenditures required are expressed here on an undiscounted basis. Thus, the average exploration funds required for the discovery of an economic deposit are the undiscounted equivalents of the "E" values presented in tables 6 and 8.

[b]: The exploration funds required to be 90 percent sure of making at least one economic discovery are approximately 2.3 times the average expenditure required.

Note: environmental breakdowns for Canada do not include "other" regions.

Possible Reasons for Observed Differences in Economic Characteristics

The marked differences observed in discovery costs, the expected value of exploration, and the average size of deposits discovered in Australia and Canada require analysis and explanation. The following possible reasons for these differences are considered.

Mineral Endowment

The observed deviations in economic characteristics may reflect fundamental differences in base metal endowment, which if true, would indicate

fundamental differences in the composition of the continental crust, mantle or geologic history in so far as they affect metal concentration. We are of the opinion that endowment is not the main reason for the perceived differences in the results of exploration in Canada and Australia. Both countries are similar in area and appear to have had a similar geologic evolution over 3.0 billion years. Similar regions of Archean, Proterozoic and Paleozoic rocks have been preserved in both countries (figures 5 and 6).

Prior to 2.5 billion years b.p. (before present) belts of volcanic rocks, and sediments derived from these volcanics, accumulated in the Archean of both countries. There is some suggestion that the Archean areas of Canada and Australia are different compositionally, with komatiitic volcanism and its associated nickel sulfide mineralisation being more strongly developed in Australia. However, Canada appears to have had more Proterozoic mafic-ultramafic igneous activity with associated nickel sulfide mineralisation, so if the Precambrian of both countries is taken together, they are not dissimilar. Acid volcanics are more common in the Canadian Archean but this may be more apparent than real as these rocks in the Australian environment are often deeply weathered and difficult to identify in surface mapping. Certainly, exploration results to date suggest that the Canadian Archean contains more known copper-zinc deposits, associated with acid volcanics, than Australia's Archean but the intensity of gold mineralization is similar: gold production is 2.7 kg per km^2 in Canada and 2.0 kg per km^2 in Australia.

Exploration Management, Science, and Technology

Success in mineral exploration is a function of the people involved, the money spent and the time over which effort is maintained (Woodall, 1983). The people in the chain of decision making and action are:

- the board of directors and/or financial investors;
- the exploration manager;
- the scientists;
- the technicians.

It is difficult to perceive significant differences between the people involved in mineral exploration in Australia and Canada. Both countries have a European heritage and the populations are very similar in cultural outlook and intellectual capacity.

Board members, investors and managers are entrepreneurial and skilled in both countries. Scientists, so critical during the conceptual phase of area selection, are competent in both countries with access to excellent education, research and in-service training facilities. Moreover, there has traditionally been a two-way flow of people and ideas between Australia and Canada. Technology and technicians, on whom the efficiency and effectiveness of geochemical surveys, geophysical surveys and drilling depend, are likewise comparable in both countries. We therefore conclude that neither management skills, nor the quality of science and technology, are valid reasons for the perceived differences in exploration results.

Personal Motivation and Investment Incentive

Although cultural outlook, intellectual capacity and training are similar in both countries, it is possible that motivation may be dissimilar. We have not made a study of personal taxation, incentives to invest (especially in exploration and mining stocks) or bonus schemes which may influence personal motivation and therefore performance. There may be some merit in doing so. Canadian companies do at times offer exploration personnel financial rewards for discoveries, but this is rarely the case in Australia. Canadian explorers may also personally invest in their exploration and mining companies more frequently than the average Australian, for whom lotteries and horse racing are the dominant outlet for their gambling instincts.

Reliability of the Data Base

The exploration funds spent in both countries are very large ($1.4 billion in Australia and $3.7 billion in Canada) and quite sufficient for average statistics to be reliable. Similarly, the statistics represent substantial time periods (24 years for Australia and 32 years for Canada), an adequate length of time for reliable trends to be established.

Effectiveness of Exploration Technology

We are of the opinion that the effectiveness of key exploration technologies differs significantly in Australia and Canada and that this is the principal reason for the contrasting exploration results. The clue is in

the return characteristics of economic deposits when these data are examined by region (table 13). The results presented only take into account the development and production phases of the mineral supply process. All deposits found to date, including discoveries made prior to 1955 in Australia and prior to 1946 in Canada are incorporated as this gives the most reliable presentation of the total scene.

It is notable that the average return characteristics of base metal discoveries in the Appalachian region of Canada are similar to those of discoveries made in similar Paleozoic rocks in eastern Australia. Most of the eastern region of Australia has significant topographic relief. The central and western parts of the Australian continent are essentially flat and there is limited incised drainage and an extensive mantle of soil and deeply weathered rock (figure 8). Its deeply-leached nature inhibits geochemical exploration and its high conductivity is a major obstacle to the use of airborne electromagnetic surveys. This type of surface condition is rare in Canada.

The surface concealment in Canada is, in contrast, largely in the form of extensive glacial debris and freshwater lakes beneath which the bedrock is essentially free from the effect of weathering. Concealed sulfide-bearing, base metal deposits can therefore exist close to the surface beneath this cover and be readily detected by electromagnetic surveys. In Australia, similar surface conditions in geophysical terms only exist to any significant extent over the Paleozoic rocks along the eastern fringe of the continent. Elsewhere, weathering has destroyed base metal sulfides near the surface and to depths often in excess of 100 meters. Such deposits now lie beneath a highly conductive near-surface zone which is difficult to penetrate with electrical geophysical prospecting techniques.

These different surface and near-surface conditions influence the nature, cost and timing of effective exploration. In Canada, relatively rapid and cheap airborne electromagnetic prospecting methods became available in the late 1940s and early 1950s and were able to penetrate the surface cover of glacial debris over large areas. Such surveys were thus a very effective and cost-efficient means of initial reconnaissance and relatively cheap ground electromagnetic surveys were very effective in defining drilling targets. In Australia these techniques were mainly ineffective. Effective geophysical mineral prospecting using electrical systems only became available in Australia when more sophisticated transient systems evolved in the 1960s and 1970s. Even then, the systems were relatively costly and unsuitable for operating in an airborne mode. Much of Australia still remains difficult and costly to explore with either electrical geophysical or geochemical methods.

The data in table 13 show that the return characteristics of base metal discoveries in the Appalachian region of Canada are indeed similar to those of discoveries made in similar Paleozoic rocks of eastern Australia. Here the weathered zone has been largely removed so that base metal exploration in both countries has been equally effective. Elsewhere the differences in exploration costs and the size of economic discoveries in the two countries are, we believe, the result of more effective exploration in Canada, which is a consequence of the different nature of the near-surface environment in the two countries. A corollary of this conclusion is that an undiscovered population of small and medium-size base metal deposits remain undetected under the complex weathered zone which covers most of Australia and awaits discovery by more advanced exploration technology.

6. AFTER-TAX VALUE OF BASE METAL EXPLORATION IN AUSTRALIA AND CANADA

Chapter 5 has presented and analyzed results for the potential, before-tax value of mineral exploration in Australia and Canada. It is now appropriate to evaluate what these assessments mean in terms of after-tax investment incentive to the mining company contemplating exploration. For this purpose, the Australian income taxation and state royalty payment systems, and the Canadian income and provincial mining taxation systems operative in 1985 are imposed on the potential value assessments, and measures of investment incentive are derived. A detailed description of the Australian income tax and royalty systems applied is given in appendix III. Similarly, the Canadian income and mining tax systems are outlined in appendix IV.

Taxation Considerations

Inflation

The existence of inflation complicates the evaluation of mining taxation effects. This is the result of two factors. First, the write-off of capital costs for tax purposes in Australia and Canada is only permitted over future periods of time. Tax allowances are taken against the current money income realized in those future time periods. Second, the amount which can be written off is limited to the actual capital costs incurred. Consequently, inflation reduces the real constant-money benefits of tax write-offs. Thus, inflation reduces investment incentive and increases government tax revenues in real terms. The higher the rate of inflation, the stronger these effects will be.

Under present conditions of relatively high and uncertain rates of inflation, it is important to consider inflation when assessing the after-tax incentive for exploration. An 8-percent per year general rate of inflation is assumed here for this purpose.

Exploration Expenditures

The Australian and Canadian mining taxation systems outlined in appendices III and IV generally permit the "expensing" of exploration

expenditures against current income as they are incurred.[24] This study does not consider the carry-forward of exploration expenditures for write-off against production income from economic deposits. Larger organizations are assumed to have sufficient income from other sources to be able to deduct exploration expenditures as they are incurred, receiving tax credits at the prevailing rate of taxation. Smaller enterprises are assumed to have no existing income, and therefore receive no tax benefit from their exploration expenditures. The "base case" for the study assumes that 75 percent of the exploration expenditures are incurred by larger companies and, thus, are expensed for tax purposes. Expensing variants of 0 percent and 100 percent are also analyzed.

Development and Production Phases

Mining taxation allowances for the development and production phases in both Australia and Canada may, generally speaking, be taken either on an individual project basis or on an integrated company basis. With the individual project basis of taxation, allowances for the development and production phases may only be taken against production income from the project. Thus, it is assumed that the mining company has no existing source of income. By "integrated company" we mean a mining company with existing sources of income from other projects. With the integrated company basis of taxation, allowances for the development and production phases may be written off as rapidly as possible against this existing income stream. The tax credits realized on an integrated company basis will, therefore, be more immediate than on an individual project basis.

The "base case" assumes that taxation is on an individual project basis. The integrated company basis of taxation is considered as a variant.

Base Case Results

The after-tax base case conditions, to which other results are compared, include those already specified for the assessment of potential value. In addition, the following taxation conditions, discussed above, are embodied in the base case:

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24. When we say that exploration expenditures are "expensed" for tax purposes, we mean that they are deducted from a company's income in the year expended for purposes of computing taxable income. This, for example, is the same way that operating costs are treated for tax purposes.

- 1985 Australian and Canadian mining taxation systems;
- general rate of inflation of 8 percent;
- 75 percent of the exploration expenditures incurred are expensed for tax purposes;
- individual project basis of taxation for development and production phases.

For after-tax base case conditions, the number of economic deposits is reduced from 17 to 16 in Australia, and from 106 to 101 in Canada. Thus, approximately 5 percent of the potentially economic deposits are rendered uneconomic by the Australian and Canadian tax systems. This indicates an important government policy inefficiency in both countries.

The cost and revenue characteristics of the economic deposits are used to assess the time distributions of average after-tax cash flows for an economic deposit, which are presented in figure 11. Average after-tax cash flow characteristics from these distributions are compared in table 18.

Based on the cash flow results shown in figure 11, further assessments have been made of the after-tax expected value of exploration in Australia and Canada and are summarized in table 19. The after-tax results are in each case compared with the potential values which were appraised in chapter 5.

In Australia, the average exploration expenditure required to find and delineate an economic deposit, $49 million potentially at the start of exploration, is reduced to $33 million on an after-tax basis. However, the average return from an economic deposit is also reduced, from $128 million to $63 million. Overall, the after-tax expected value of an economic discovery is (63-33) = $30 million. The marginal economic character of base metal exploration in Australia under the assumed conditions is also reflected by the 11-percent after-tax discounted cash flow rate of return, as compared to the 12-percent potential rate of return, and the 8-percent cost of capital.

In Canada, the average exploration expenditure per economic deposit discovered is reduced as shown in table 19 from $27 million to $14 million on an after-tax basis, the $13 million difference representing the associated tax credits discounted back to the start of exploration. The average return is likewise lowered from $188 million potentially at the start of exploration to an after-tax value of $84 million. In this case, the difference of $104 million is the discounted equivalent of the time distribution of federal and provincial mining taxation payments portrayed in figure 11. Thus, the after-tax expected value of base metal exploration in Canada per economic discovery is (84-14) = $70 million. The corres-

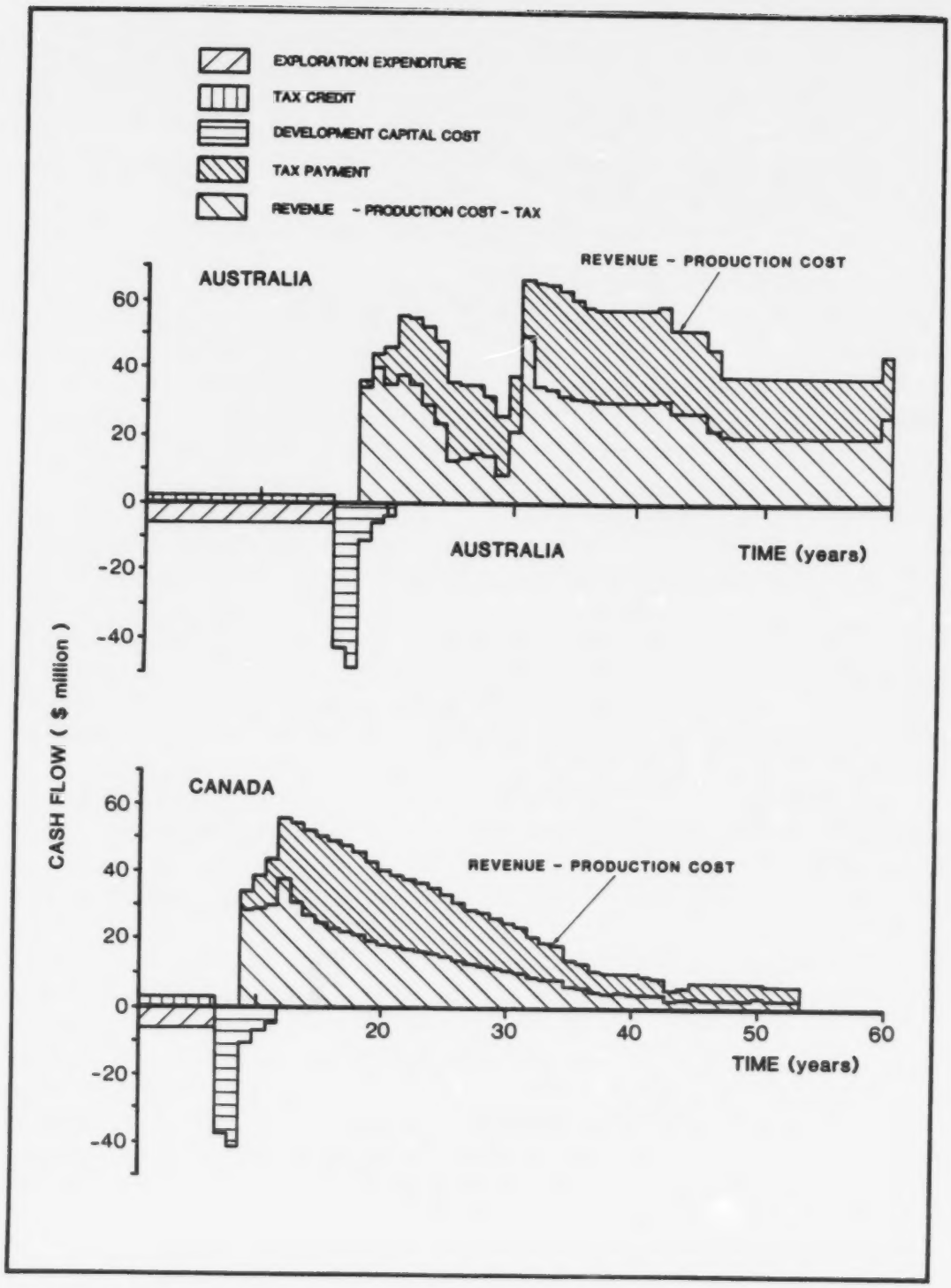

Figure 11. After-Tax Time Distribution of Average Cash Flow Characteristics for an Economic Base Metal Deposit Under Base Case Conditions

Table 18

AFTER-TAX ASSESSMENT OF AVERAGE CASH FLOW CHARACTERISTICS FOR AN ECONOMIC BASE METAL DEPOSIT UNDER BASE CASE CONDITIONS

Characteristic	Australia	Canada
Time periods (years):		
Exploration phase	15	6
Development phase (maximum)	5	5
Production phase (maximum)	43	48
Undiscounted values ($ million):		
Revenue	3,585	1,767
Exploration expenditure	87	36
Development capital cost	113	101
Production cost	1,582	636
Tax and royalty payments	871	545
Cash flow	932	449

Table 19

AFTER-TAX ASSESSMENT OF EXPECTED VALUES FOR BASE METAL EXPLORATION IN AUSTRALIA AND CANADA UNDER BASE CASE CONDITIONS

	Australia		Canada	
Category	Potential Value	After-Tax Value	Potential Value	After-Tax Value
Number of economic discoveries	17	16	106	101
Average exploration expenditure (E, $ million)	49	33	27	14
Average return (R, $ million)	128	63	188	84
Expected value (EV, $million)	79	30	161	70
Rate of return (percent)	12	11	22	19

ponding after-tax rate of return is shown in table 19 to be 19 percent, as compared to the 22 percent potential rate of return.

Study results demonstrate that overall tax burdens in both Australia and Canada are substantial. Levels of taxation in the two countries may be illustrated by the relationship between net tax payments and after-tax cash flows as portrayed in figure 12. In Australia, government taxation payments represent about 48 percent of the before-tax cash flows of economic deposits. Consequently, mining companies receive 52 percent of the actual value realized in the form of after-tax cash flows. About 88 percent of the payments made to government in Australia are commonwealth income tax payments, the remaining 12 percent representing state royalties. The burden of taxation is shown to be greater in Canada; net tax payments are equivalent to about 55 percent of before-tax cash flows, with the remaining 45 percent being returned to the mining companies. Government taxation revenues in Canada break down into the following components: 47 percent is paid as federal corporate income tax, 19 percent is provincial corporate income tax, and 34 percent is collected as provincial mining tax.

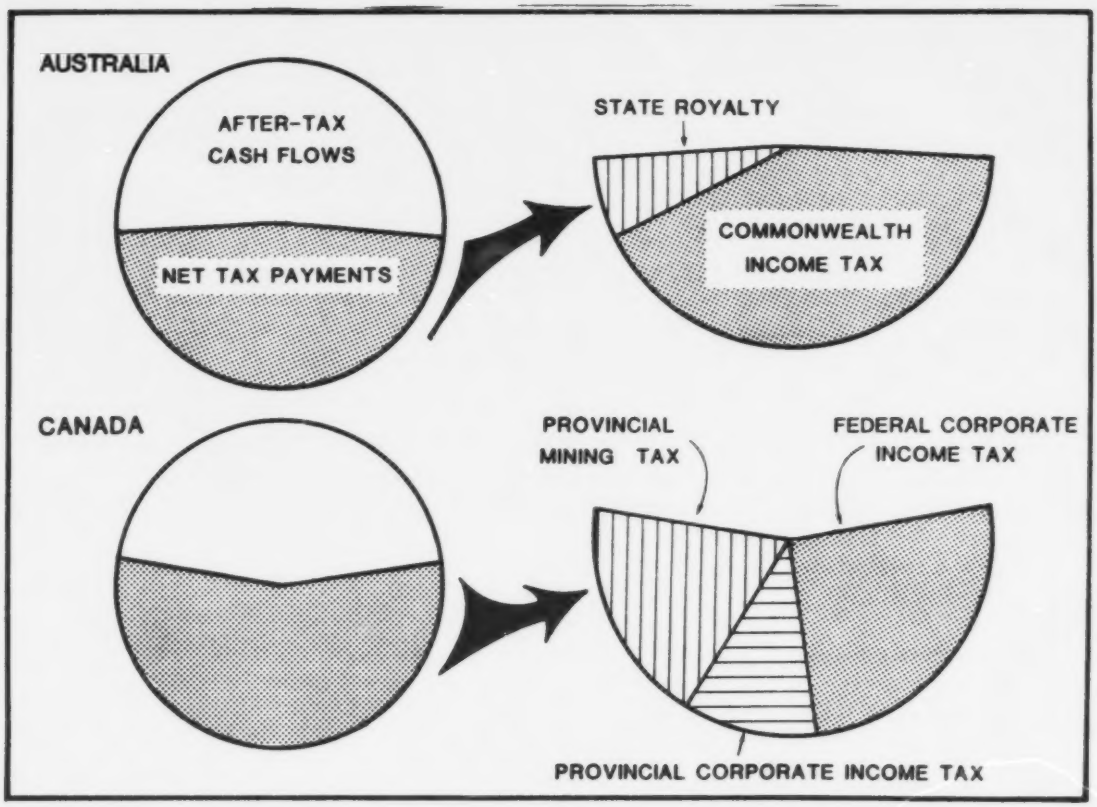

Figure 12. Level and Components of Government Taxation Payments

After-tax assessments for the development and production phases of the cash flow distributions illustrated in figure 11 are separately evaluated in table 20. These results reconfirm that base metal deposits discovered in Australia and Canada to date are similar in terms of average profitability, as shown by the after-tax rates of return, but Australian discoveries are typically larger in size, as shown by the comparative after-tax returns per economic deposit.

Table 20

AFTER-TAX ASSESSMENT OF EXPECTED VALUES FOR DEVELOPMENT AND PRODUCTION PHASES IN AUSTRALIA AND CANADA UNDER BASE CASE CONDITIONS

Category	Australia	Canada
Return per economic deposit ($ million)	195	133
Rate of return (percent)	27	27

Note: the expected or average return per economic deposit is assessed as a net present value at 8 percent discounted back to the start of development.

Tax Write-Off Variants

The effects of the following three sets of exploration and development tax write-off provisions are considered here.

1. Base Case Conditions: 75-percent expensing of exploration expenditures; individual project basis of taxation.

2. Tax Variant 1: 0-percent expensing of exploration expenditures; individual project basis of taxation.

3. Tax Variant 2: 100-percent expensing of exploration expenditures; integrated company basis of taxation.

Results are presented in table 21. The ability to expense exploration costs for tax purposes is of great benefit in both countries, as illustrated by observed differences in the average after-tax exploration expenditures

Table 21

AFTER-TAX ASSESSMENT OF EXPECTED VALUES FOR BASE METAL EXPLORATION IN AUSTRALIA AND CANADA AS A FUNCTION OF TAX WRITE-OFF VARIANTS

Category and Tax Variant	Australia		Canada	
	Potential Value	After-Tax Value	Potential Value	After-Tax Value
Number of economic discoveries	17		106	
Base case		16		101
Tax Variant 1		16		101
Tax Variant 2		17		110
Average exploration expenditure (E, $ million)	49		27	
Base case		33		14
Tax Variant 1		51		28
Tax Variant 2		26		8
Average return (R, $ million)	128		188	
Base Case		63		84
Tax Variant 1		63		84
Tax Variant 2		64		86
Expected value (EV, $million)	79		161	
Base case		30		70
Tax Variant 1		12		56
Tax Variant 2		38		78
Rate of return (percent)	12		22	
Base case		11		19
Tax Variant 1		9		15
Tax Variant 2		12		23

required to find and delineate an economic deposit. While there is only a marginal difference between individual project and integrated company tax bases in Australia, the integrated company basis of taxation is quite advantageous in Canada, particularly with respect to the number of deposits justifying development after tax. The contrast between Australian and Canadian results in this regard is mainly attributable to the generally higher depreciation rates at which capital costs can be written off for tax purposes in Canada.

Generally speaking, in both countries, there is a marked difference between the tax treatment of junior exploration enterprises (variant 1) and established mining companies (variant 2), as shown by the compara-

tive expected values per economic discovery and expected rates of return for base metal exploration in table 21.[25]

Metal Price Variants

An after-tax assessment of expected values for base metal exploration in Australia and Canada as a function of metal price is summarized in table 22. Exploration is shown to be a decidedly uneconomic proposition in both countries at lower-limit prices. As metal prices increase, there are sharp improvements in the average return characteristics associated with the discovery of an economic deposit and, consequently, in the overall expected value measures. While these results are similar to those presented in chapter 5 on a potential value basis (table 10), it should be noted that since the economics of base metal exploration is closer to the margin after tax, the sensitivity of expected values to metal price uncertainties is more critical.

Suggestions for the Analysis of Mining Taxation Policy

The subject of taxation has been introduced in this chapter to address the question of investment incentive to the mining company deciding on new or continuing exploration. While the methodology and data base developed have been used here to assess the economics of base metal ex-

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25. In recent years, Canadian government policy with respect to the write off of investment in "flow-through shares" for tax purposes has corrected this imbalance by giving junior exploration enterprises a similar tax break to that available to established mining companies.

    Flow-through shares were made possible through changes in tax legislation and since 1983 have evolved as an important source of equity financing for the Canadian mining industry.

    Flow-through shares may be defined as an interest acquired in a mining venture in which the tax deductions resulting from the expenditure of the invested funds are attributable (or "flow-through") to the original investor on whose behalf the activity is undertaken. More specifically, under current Canadian tax laws, the tax deductions resulting from exploration activities can be attributed to the investor of equity funds in mining.

    See B.A. Kalymon, Flow-Through Share Financing, Working Paper No. 39, (Kingston, Ontario: Centre for Resource Studies, May 1987.

Table 22

AFTER-TAX ASSESSMENT OF EXPECTED VALUES FOR BASE METAL EXPLORATION IN AUSTRALIA AND CANADA AS A FUNCTION OF METAL PRICE

Country and Price Variant	Number of Economic Discoveries	Average Exploration Expenditure, E ($ million)	Average Return, R ($ million)	Expected Value, EV ($ million)	Rate of Return (percent)
Australia					
Lower-limit prices	4	49	1	-48	1
Expected prices	16	33	63	30	11
Upper-limit prices	29	23	183	160	22
Canada					
Lower-limit prices	16	35	5	-30	3
Expected prices	101	14	84	70	19
Upper-limit prices	162	9	158	149	30

ploration in Australia and Canada, they could readily be applied to mining taxation policy.[26]

Clearly, equitable mining taxation and royalty regimes are in the best long-term interests of both industry and government. Only in this way will adequate investment for long-term exploration and development of the mining sector be forthcoming.

The concept of an equitable taxation system is inherently difficult to apply because of the discovery risk, geological variability, and market uncertainties inherent in mining. In Australia and Canada, the situation is further complicated by the division of responsibility which exists between federal and state, provincial, and territorial governments.

Mining taxation policy should be both realistic and effective, and it should have a minimum of unexpected side effects. To achieve these results, it must be based on a factual understanding of the mining sector. In other words - what are the potential costs and revenues to be shared? In this way, the effects of mining taxation systems can be meaningfully assessed and more stable, flexible, and enduring policies formulated.

The present study provides a basis for estimating, examining, and comparing the potential value of the base metal mining sector in Australia and Canada, assessed from the viewpoint of society as a whole. This potential value represents the maximum that is available for sharing between industry and government - the "pie" which exists prior to mining taxation and royalty considerations.

It should be understood that a mining taxation system affects not only the industry-government shares, but also the size of the pie. Therefore, actual and proposed taxation regimes should be evaluated through their effect on all three of: the actual value to society which would be realized; the after-tax investment incentive remaining for mining companies; and the government taxation and royalty revenues which would be collected. Although governments no doubt have many varied mineral policy objectives, the realization of which are affected by their system of mining taxation, an understanding of these three types of direct effects is fundamental in judging the relative desirability of alternative mining taxation systems and in formulating mining taxation policy. Assessments of these three criteria of desirability for actual and contemplated mining taxation systems support policy formulation by crystalizing the trade-offs involved in moving from one taxation system to another.

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26. This has been the main purpose of similar work carried out at the Centre for Resource Studies in Canada since 1976. See: B.W. Mackenzie and M.L. Bilodeau, Effects of Taxation on Base Metal Mining in Canada (Kingston, Ontario: Centre for Resource Studies, 1979, 190 pp.); and B.W. Mackenzie and C.H. Pye, Effects of Public Policy on Investment Demand: the Case of Taxation in Canadian Base Metal Mining, working paper no. 26 (Kingston, Ontario: Centre for Resource Studies, 1982, 58 pp.

7. CONCLUSION

This paper examines the economic relationship between real expenditures for base metal exploration and the potential returns from the resulting discoveries. It focuses on the modern era of base metal exploration, which began in Australia during the 1950s and in Canada after World War II. The periods analyzed are 1955-78 and 1946-77 for the two countries, respectively. The economics of base metal exploration is assessed on both a before-tax, potential value basis, and on an after-tax basis. All direct costs and revenues associated with the exploration, development, and production phases of mineral supply are included.

The purpose of the paper is to assess and explain similarities and differences between the two countries in a way that is useful for corporate planning and the analysis of government policy. The main conclusion of the analysis is that the economics of base metal exploration in Australia is quite different from the Canadian experience.

Overall potential value results for a set of most-likely base case conditions indicate that, while base metal exploration in Australia has been rather marginal overall, decidedly positive expected values have been realized in Canada. The level of base metal exploration expenditures in Canada over the study period is found to be about three times that in Australia, but the resulting number of economic discoveries assessed is more than six times greater. An economic base metal deposit in Australia costs twice as much and takes twice as long to find and delineate as does one in Canada. On the other hand, the economic base metal deposits discovered in Australia are typically twice as large as those in Canada.

Time trends in the economics of base metal exploration reflect the combined effects of advances in technology and depletion. While the time trend evidence in both Australia and Canada is inconclusive, it does not, in general, support the hypothesis that the economics of mineral exploration has deteriorated with time.

The results of the study indicate that exploration economics is highly sensitive to market prices. Thus, the uncertainty associated with forecasts of metal prices represents an important risk in exploration planning and government policy analysis. Differences between the base metal exploration results in Australia and Canada are shown to be a function of price.

Olympic Dam in Australia and Kidd Creek in Canada are the most important base metal deposits discovered in the two countries during the respective study periods. These two deposits - among 17 economic dis-

coveries in Australia and 106 economic discoveries in Canada - represent a substantial part of the base metal potential. If these very rare deposits did not occur, the economics of base metal exploration in Australia and Canada would be impoverished.

As a consequence of the variability in tonnage, grade, and other geologic characteristics among economic deposits, there is typically a wide range of possible returns distributed around the average return for an economic base metal discovery. For example, assuming expected metal prices, the results for Australia show a 140-times difference in value between the lower-decile and upper-decile economic deposits. Thus, there is really no such thing as a "typical deposit". Flexibility is required in government policies to accommodate the wide range of returns inherent in mining equitably and efficiently.

The high risk associated with the discovery of an economic mineral deposit results in a large difference between the average exploration expenditure required to find and delineate an economic deposit and the exploration funds required to ensure success. For typical Australian conditions, exploration funding of $189 million would be required to be 90 percent sure of making at least one economic discovery; $80 million would be necessary for base metal exploration in Canada. These funding levels to ensure success compare with average exploration expenditure requirements per economic discovery of $82 million and $35 million, respectively.

The Australian income tax and state royalty payment systems, and the Canadian income and provincial mining taxation systems operative in 1985, are imposed on the potential value assessments, and measures of investment incentive are derived. Approximately 5 percent of the potentially economic deposits are rendered uneconomic by the Australian and Canadian tax systems, indicating an important government policy inefficiency. The tax burdens in both countries are shown to be substantial. Government taxation payments represent 48 percent and 55 percent of the before-tax cash flows in Australia and Canada respectively. Results illustrate how the study methodology and data base could be applied to the formulation of mining taxation policy. To be realistic and effective, mining taxation policy must be based on a factual understanding of the mining sector in the long term, from the start of exploration.

Possible reasons for the marked differences observed in discovery costs, the expected value of exploration, and the average size of deposits discovered in Australia and Canada are examined. Base metal exploration in the two countries utilizes comparable geological expertise, exploration technology, and management skills. Furthermore, personal motivation and investment incentive are judged to be similar. Thus, there are two possible explanations for the overall differences in the economics of base

metal exploration. First, there may be a fundamental difference in the base metal endowment characteristics of the two countries, with fewer, larger deposits actually occurring in Australia. Second, base metal exploration in Australia may be much more difficult and less effective than in Canada, reflecting the productivity of geophysical exploration in glaciated Canadian environments as compared to the problem of detecting medium and small deposits beneath the deeply weathered near-surface zone that blankets most of Australia.

More detailed study results show that the return characteristics of base metal discoveries in the Appalachian region of Canada are comparable to those of discoveries made in similar Paleozoic rocks of eastern Australia. Furthermore, it is only in the Paleozoic environment of Australia that the weathered zone has been removed, so that in these regions in both countries base metal exploration has probably been equally effective. This evidence indicates that the overall differences in exploration costs and the size of economic discoveries in the two countries are the result of more effective exploration in Canada to date. It further suggests that an undiscovered population of small and medium-size base metal deposits under the complex weathered zone covering most of Australia awaits discovery by more advanced exploration technology.

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APPENDIX I

POSSIBLE ECONOMIC DISCOVERIES FOR EVALUATION: AUSTRALIA

Classification by Exploration Environment and Discovery Date

Paleozoic Region

	Discovery Date			
	Pre-1955	1955-62	1963-70	1971-78
BELTANA			X	
BURRAGA	X			
CADIA	X			
CAPE HORN		X		
CAPTAIN'S FLAT	X			
CHESNEY	X			
CSA EAST		X		
CSA WEST	X			
CURRAWONG				X
ELURA				X
FARRELL	X			
GALWADGERE			X	
GREAT COBAR	X			
HERCULES	X			
KANMANTOO			X	
LIONTOWN			X	
LYELL COMSTOCK	X			
MAGNET	X			
MOUNT CANNINDAH	X			
MOUNT CHALMERS	X			
MOUNT LYELL	X			
MOUNT MORGAN	X			
NEW COBAR	X			
NORTH LYELL	X			
NYMAGEE	X			
PILLARA SPRING				X
QTS				X
QUE RIVER				X
ROSEBERRY	X			
SORBY HILLS				X
THALANGA				X
WEST LYELL	X			
WILGA				X
WOODLAWN			X	

Precambrian Regions

	Discovery Date			
	Pre-1955	1955-62	1963-70	1971-78
(i) Archean Environment				
ANGELO			X	
GOSSAN HILL				X
MONS CUPRI			X	
SCUDDLES				X
TEUTONIC BORE				X
WHIM CREEK	X			
WHUNDO	X			
(ii) Proterozoic Environment				
ATTUTRA		X		
BROKEN HILL	X			
BROWN'S		X		
BURRA	X			
CATTLE GRID				X
DUCHESS COPPER	X			
DUGALD RIVER	X			
FITZPATRICK				X
GECKO			X	
HILTON	X			
HYC		X		
INTERMEDIATE			X	
ISA COPPER	X			
ISA SILVER-LEAD-ZINC	X			
IVANHOE			X	
JUNO			X	
KAPUNDA	X			
KOONGIE PARK				X
LADY ANNIE	X			
LADY LORETTA			X	
MAMMOTH	X			
MARTINS			X	
MOONTA	X			
MOUNT ELLIOTT	X			
MOUNT GUNSON	X			
MOUNT LYNDHURST				X

(ii) Proterozoic Environment (continued)

	Discovery Date			
	Pre-1955	1955-62	1963-70	1971-78
OLYMPIC DAM				X
ORLANDO		X		
PARABARANA				X
PEKO	X			
REDBANK			X	
WALLAROO	X			
WARREGO		X		
WEE MACGREGOR	X			
WHITE'S	X			
WOODCUTTERS			X	

APPENDIX II

POSSIBLE ECONOMIC DISCOVERIES FOR EVALUATION: CANADA

Classification by Exploration Environment and Discovery Date

Appalachian Region

	Discovery Date				
	Pre-1946	1946-54	1955-62	1963-70	1971-77
BRUNSWICK 6		X			
BRUNSWICK 12		X			
BUCHANS	X				
CAPELTON	X				
CAPE RAY					X
CARIBOU			X		
CLEARWATER			X		
CUPRA			X		
DANIEL'S HARBOUR				X	
EAST				X	
EUSTIS	X				
GAY'S RIVER					X
GASPE COPPER MOUNTAIN	X				
GREAT BURNT LAKE				X	
GULLBRIDGE	X				
HALFMILE LAKE			X		
HUNTINGTON		X			
KEY ANACON		X			
LITTLE BAY	X				
LITTLE RIVER		X			
MADELEINE				X	
MCLEAN		X			
MING				X	
MURRAY BROOK			X		
NEEDLE MOUNTAIN	X				
ORIENTAL NO. 2		X			
RAMBLER MAIN	X				
ROTHERMERE		X			
SALMON RIVER			X		
SOLBEC			X		
STIRLING	X				
STRATMAT				X	

Appalachian Region (continued)

	Discovery Date				
	Pre-1946	1946-54	1955-62	1963-70	1971-77
SUFFIELD	X				
THIRD PORTAGE LAKE			X		
TILT COVE	X				
WALTON			X		
WEDGE			X		
WEEDON	X				
WHALESBACK			X		

Shield Region

AGRICOLA LAKE					X
ALDERMAC	X				
AMOS	X				
AMULET A	X				
AMULET C	X				
AMULET F	X				
ANDERSON LAKE				X	
ANGLO AMERICAN			X		
BARVALLEE			X		
BARVUE		X			
BELFORT		X			
BELL ALLARD			X		
BIG NAMA CREEK			X		
BIRCH LAKE		X			
BOB	X				
BOUZAN			X		
BRUCE	X				
CAMPBELL MAIN	X				
CEDAR BAY	X				
CENTENNIAL				X	
CHIBOUGAMAU EXPLORERS		X			
CHISEL LAKE			X		
COLDSTREAM		X			
CONIAGAS		X			
COOKE				X	
COPPER CLIFF			X		
COPPERCORP		X			

Shield Region (continued)

	Discovery Date				
	Pre-1946	1946-54	1955-62	1963-70	1971-77
COPPER-LODE A				X	
COPPER-LODE E				X	
COPPER-MAN	X				
COPPER RAND		X			
CORBET			X		
CORONATION		X			
CUPRUS	X				
DELBRIDGE				X	
DETOUR A1					X
DETOUR A2					X
DETOUR B					X
DICKSTONE	X				
DIXIE					X
DUNRAINE	X				
EAST SULLIVAN	X				
EAST WAITE		X			
EMBURY LAKE					X
ERRINGTON	X				
F GROUP				X	
FLEXAR		X			
FLIN FLON	X				
FOX			X		
GARON LAKE			X		
GECO		X			
GHOST LAKE			X		
GOLDEN MANITOU	X				
GRANDROY		X			
GRASSET LAKE					X
GWILLAM					X
HACKETT				X	
HENDERSON			X		
HIGH LAKE			X		
HOOD RIVER					X
HOPE LAKE				X	
HORNE	X				
HYERS ISLAND	X				
ICON				X	
INDIAN MOUNTAIN		X			

Shield Region (continued)

	Discovery Date				
	Pre-1946	1946-54	1955-62	1963-70	1971-77
IZOK LAKE					X
JACULET		X			
JAMELAND				X	
JAMIESON				X	
JOLIET	X				
JOUTEL			X		
JUNE				X	
JUNGLE			X		
KAM KOTIA	X				
KIDD CREEK				X	
KOKKO CREEK		X			
LACORNE	X				
LEMOINE					X
LESSARD					X
LOST LAKE					X
LOUVEM				X	
LOUVEM ZINC					X
LYON LAKE					X
MAGUSI					X
MATTABI				X	
MATTAGAMI			X		
MERRILL ISLAND	X				
MILLENBACH				X	
MUNRO COPPER		X			
NANISIVIK			X		
NEW CALUMET	X				
NEW HOSCO			X		
NEW INSCO					X
NORBEC			X		
NORITA				X	
NORMETAL	X				
NORTH STAR		X			
OLD WAITE	X				
ORCHAN			X		
OSBORNE LAKE		X			
PATER		X			
PERRY			X		
PINEBAY			X		

Shield Region (continued)

	Discovery Date				
	Pre-1946	1946-54	1955-62	1963-70	1971-77
POIRIER			X		
PORTAGE			X		
PREISSAC	X				
QUEBEC CHIBOUGAMAU			X		
QUEMONT		X			
RAIL LAKE				X	
REED LAKE				X	
RIOCANEX OBALSKI					X
ROBATAILLE			X		
ROD				X	
RUTTAN				X	
SCHIST LAKE	X				
SCHUMACHER COPPER			X		
SCOTT					X
SHERRIDON	X				
SOUTH BAY				X	
SPRINGER	X				
SPRUCE POINT					X
STALL			X		
STURGEON				X	
SYLVIA					X
TEMAGAMI		X			
TRIBAG			X		
TURNBACK	X				
VAMP LAKE	X				
VAUZE			X		
VENDOME		X			
VERMILLION	X				
WADEN BAY		X			
WAITE DUFAULT	X				
WESTARM					X
WEST MACDONALD	X				
WHITE LAKE				X	
WILLECHO		X			
WILLROY		X			
WIM				X	

Cordilleran Region

	Discovery Date				
	Pre-1946	1946-54	1955-62	1963-70	1971-77
ADANAC				X	
AFTON					X
ANNEX				X	
ANNIV					X
BEAR TWIT					X
BELL			X		
BENSON				X	
BERG				X	
BEST CHANCE	X				
BETHLEHEM			X		
BIG BULL & TULSEQUAH CHIEF	X				
BLUEBELL		X			
BLUE GROUSE		X			
BONANZA	X				
BOSS MOUNTAIN				X	
BRENDA				X	
BRITANNIA	X				
CARIBOO BELL				X	
CASINO				X	
CATFACE			X		
CHUCHUA CREEK					X
CIRQUE					X
COPPER MOUNTAIN	X				
COWLEY PARK		X			
CRAIGMONT			X		
DAVIS KEAYS				X	
DY					X
ENDAKO			X		
FARO				X	
GALORE CREEK			X		
GAYNA RIVER					X
GEM				X	
GIBRALTAR				X	
GLACIER GULCH			X		
GOLDSTREAM					X
GRANDUC		X			
GRANISLE			X		

Cordilleran Region (continued)

	Discovery Date				
	Pre-1946	1946-54	1955-62	1963-70	1971-77
GRUM					X
HARPER CREEK				X	
HB		X			
HIDDEN CREEK	X				
HIGHMONT			X		
HOWARD'S PASS					X
HUCKLEBERRY				X	
INDIAN CHIEF	X				
INGERBELLE				X	
ISLAND COPPER				X	
JA					X
JASON					X
JERSEY		X			
KEEWENAW	X				
KITSAULT			X		
KUTCHO CREEK					X
LITTLE CHIEF			X		
LORNEX				X	
LUCKY JIM	X				
LYNX			X		
MAGGIE				X	
MAGNUM			X		
MEL					X
MINERAL KING		X			
MINTO					X
MORRISON				X	
MOTHER LODE AND SUNSET	X				
MYRA FALLS				X	
NADALEEN RIVER					X
OK				X	
ORO DENORO	X				
PHOENIX	X				
RED					X
RED MOUNTAIN				X	
REDSTONE COPPER			X		
REEVES	X				
ROBB LAKE					X
SAM GOOSLY				X	

Cordilleran Region (continued)

	Discovery Date				
	Pre-1946	1946-54	1955-62	1963-70	1971-77
SCHAFT CREEK				X	
SNOWSHOE	X				
SULLIVAN	X				
SUNRO			X		
SUSTUT					X
SWIM LAKE				X	
TOM		X			
TROJAN	X				
TROUT LAKE				X	
VALLEY COPPER				X	
VANGORDA		X			
WAR EAGLE	X				

Other Regions

CORONET				X	
ECLIPSE				X	
GREAT SLAVE REEF					X
PINE POINT 1		X			
PINE POINT 2				X	
PINE POINT 3					X
PINE POINT 4					X
POLARIS					X
PYRAMID				X	

APPENDIX III

AUSTRALIAN INCOME TAX AND ROYALTY PAYMENT SYSTEMS

Although there are a number of special features in the Australian tax system affecting the mining industry, in most respects the legislation applies in the same manner for all types of corporations.

Cash Flow Format

Revenue
- State Royalty Payments
- Operating Costs

Net Income Before Allowances
- Carried Loss (from year X-1)
- New Deductions: Exploration Expenditures
  Capital Expenditures for Normal Depreciable Assets
  Capital Expenditures for Special Mining Assets
  Transportation and Port Facilities
  Payments for Purchase of Mining Property

If positive: Income for Australian Income Taxation
If negative: Carried Loss (for year X+1)
Australian Income Taxation

Carried Loss

Revenue and deductions may be "pooled" within a mining company for Australian income tax purposes.

To the extent that net income is not available to absorb new deductions in any given year (and any carried loss from the previous year), the balance constitutes a "carried loss" which may be carried forward to the next year for deduction. Losses may be carried forward in this manner for up to seven years before they are extinguished. From 1984, companies are allowed to transfer losses between individual companies in their group where there is 100 percent common ownership.

New Deductions

The taxation system makes a distinction between capital expenditures for the following two types of assets.

i Normal Depreciable Assets - hoists, mine plant and machinery, processing plant and machinery,[27] power and water facilities.

ii Special Mining Assets - mine access and development, all buildings, "adjacent" housing and townsite facilities.

"New Deductions" are based on capital expenditures, and are determined according to the following rules.

i Exploration Expenditures
Includes mapping, geological, geophysical and geochemical work, drilling, exploration shafts and development, prior to making a decision to commence mining. Feasibility studies, metallurgical testing and similar pre-development work are usually allowable. Exploration expenditures are deductible in the year incurred, the deduction being limited to the amount of income available from any source after all other deductions have been taken. Undeducted expenditures may be accumulated and deducted against any subsequent mining income.

ii Capital Expenditures for Normal Depreciable Assets
Basically, there are two rates available.
A. General plant, equipment and machinery - 20 percent straight-line.
B. Heavy duty machinery - 33 1/3 percent straight-line.[28]

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27. Processing plant and machinery used exclusively in the milling and concentration phases of a mining operation are nominally special mining assets. However, they are also eligible for normal depreciation if election is made because such equipment is normally depreciated in other industries. In view of the higher rate of write-off, it is assumed here that such an election to transfer processing assets is made. Such an election would not be made only if and when it was considered that a "carried loss" created by the election would be imperilled by the seven year loss carry forward limitation.
28. It may be assumed that typically 15 percent of underground mine plant and machinery, and 20 percent of open pit mine plant and machinery qualify as heavy duty machinery.

Alternatively, a company may opt for declining-balance depreciation at 1.5 times the applicable straight-line rate (i.e., at 30 percent or 50 percent).

When the remaining mine life is less than (1/depreciation rate), depreciation may be taken in equal annual amounts over the remaining life.

Deductions must be taken. The applicable rate is determined by referencing the depreciation rates published by the Commissioner of Taxation. If the published straight-line rate for an asset, combined with the current "loading" of 18 percent, is 20 percent or less, then the 20 percent rate applies. If the published straight-line rate, combined with the 18 percent loading, exceeds 20 percent, then the 33 1/3 percent rate applies.[29]

iii Capital Expenditures for Special Mining Assets

These capital expenditures are deductible at 10 percent per year on a straight-line basis when the remaining mine life is ten years or more; or by equal annual amounts where the remaining mine life is less than ten years.

A deduction may or may not be taken. It would not be taken if a "carried loss" so created was considered to be imperilled by the seven year loss carry forward limitation.

Buildings which are not specifically situated on the mining property or at the treatment site may be eligible to be written off over 40 years (i.e. 2.5 percent straight-line) if the buildings are used in the income-producing activities of the business. This special deduction does not apply to buildings which are primarily used for residential purposes.

iv Transportation Facilities

Includes capital expenditure for roads, railways and pipelines for use in transporting products from the mine site. Port development costs for dredging, breakwaters, navigational aids and surveys are also included. Road vehicles, railway rolling stock, ships, etc, are not covered by this provision but are eligible for depreciation and investment allowance as "normal depreciable assets".

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29. The published straight-line rate is, theoretically, (1.0/useful life of asset) x 100 percent. The "loading" represents a provision for accelerated depreciation.

These capital expenditures are deducted at 10 percent or 5 percent straight-line depreciation at the taxpayer's option. This deduction must be taken. The 10 percent rate would normally be selected unless a "carried loss" created by the deduction was endangered by the seven year loss carry forward limitation.

v Port Facilities
Jetties and any plant and machinery, such as cranes, conveyors and shiploaders, are eligible for depreciation and investment allowance as "normal depreciable assets" as outlined above. The provision of housing and townsite facilities at port sites is not deductible.

vi Payments for Purchase of Mining Property
The value of various types of assets specified in the purchase agreement for a mining property are allowable as "new deductions". Deductions may not exceed the vendor's actual expenditure on the property, reduced by any deductions already claimed. The purpose of this limitation is to place the purchaser in the same position with respect to the deductions as the vendor was immediately prior to the sale.

Australian Income Tax

Australian income tax is imposed at the normal corporate rate of 49 percent of the income of resident companies (basically companies incorporated in Australia).

Tax is payable in the year following the year for which it is assessed. Since it is paid in quarterly installments, this effectively means an 18-month time lag for companies which have a June 30th year end.

Non-resident companies (e.g., a Canadian company operating in Australia through a branch) are subject to an additional tax of 5 percent of taxable income.

Gold mining income is completely exempt from Australian income tax provided:

i more than half the mine's income is from gold, or
ii more than 40 percent of the income of a gold-copper mine is from gold.

As the gold mining income is exempt, the expenditure incurred is not an allowable deduction. This exemption applies to both residents and non-residents.

For joint ventures, the costs and products are shared among the partners as specified in the agreement. Each partner is individually taxed according to the rules outlined above. This in effect allows for taxation of each partner on an integrated company basis, where otherwise, an individual project basis of taxation would apply.

Australian taxation of mining income is in no small part influenced by the substantial foreign ownership in the Australian mining industry and government policies directed towards its control. In this regard, special policy guidelines apply for the development of major mining projects. Briefly stated, the Australian government generally requires a minimum of 50 percent Australian equity (75 percent in the case of uranium) for new mining developments. However, if there are difficulties in securing local Australian equity, the government may allow a project to proceed with a lower level of domestic equity.

Withholding taxes on remittance to overseas residents are at the standard rates of 10 percent on interest and 30 percent (or 15 percent in the case of Canada and other countries where a tax treaty applies) on dividends. However, profits of an Australian branch of a non-resident company can be remitted to the foreign head office free of withholding tax. However, a branch profit tax of 5 percent must be paid, as mentioned above with respect to nonresidents.

State Royalty Payments

Format

Metal Revenue (cif market)
- Smelter Payments and Transportation Costs

Concentrate Revenue (fob mine)
- Operating Cost
- Depreciation Allowance (assume straight line over mine life)

Net Income

NEW SOUTH WALES

Broken Hill Mines

i Traditional regime:

4% on first $400,000 of net income;
6% on next $400,000 of net income;
8% on next $400,000 of net income;
up to 50% on net income exceeding $9,200,000.

ii New arrangement from January 1985: flat-rate royalty varying with mining depth and grade. For example, the North mine currently pays a royalty of 20-21 percent of net income.

Cobar Mines

i Traditional regime:

2% on first $200,000 of net income;
3% on next $200,000 of net income;
4% on next $200,000 of net income;
up to 8% on net income exceeding $1,200,000.

ii New arrangement announced May 1985.

Other Mines:
4% of concentrate revenue

NORTHERN TERRITORY

18 percent of net income. Depreciation is calculated on a straight-line basis over the shorter of economic asset life or 15 years. Accumulated losses from previous years can be carried forward indefinitely.

This system will eventually apply to all mines in the Territory. In the cases of uranium mines and mines operating or under construction before July 1, 1982, application of the new system is deferred.

QUEENSLAND

The preferred approach whenever practicable is to levy royalties as a "percentage of value". The basic rate is 10 percent of the sales revenue of the mineral product as loaded and ready for shipment. This rate applies to petroleum, natural gas, exported bauxite and some other minerals. A variety of other royalties also apply. A major review of the royalty system commenced in mid-1987.

At Mount Isa Mines, where there is considerable downstream processing with no arms-length sale of the ore, the royalty scheme is based on the tonnes of ore mined as follows:

- copper ore and lead/zinc/silver ore are separately assessed;
- basic royalty is $2.00 per tonne of ore mined varying with the ratio of the current realizable value of the contained metals per tonne of ore to the average realizable value in 1973-74.

For other base metal mines and gold mines, the royalty levied is the greater of 2% of concentrate revenue exceeding $30,000 or 5% of net income exceeding $30,000.

A 5% of sales revenue royalty rate applies to open cut coal for export markets because "adequate rail freight profits are derived". For underground coal mines, the royalty rate is 4%.

From mid-1987, the government increased the royalty rate on the titanium minerals, rutile and ilmenite; monazite and zircon from 2% to 5% of concentrate revenue.

SOUTH AUSTRALIA

Olympic Dam Mine:
special royalty regime applies

General:
2.5% of concentrate revenue

TASMANIA

General:

	Lower of	
Net Income	Concentrate Revenue	Net Income
<$10 mil.	2.5%	5%
$10-15 mil.	3%	6%
>$15 mil.	3.5%	7%

VICTORIA

Gold: nil

Other:
1.75% of concentrate revenue

WESTERN AUSTRALIA

Gold: nil

Nickel, Tin:
2.5% of metal revenue

Cobalt, Silver, Platinoids:
2.5% of concentrate revenue

Copper, Lead, Zinc, Tungsten and others:
5% of concentrate revenue

Diamonds:
special royalty regime applies

APPENDIX IV

CANADIAN INCOME AND MINING TAXATION SYSTEMS

Federal Corporate Income Tax

Cash Flow Format:

Revenue
- Operating Cost
- Capital Cost Allowance @ 30% db (optional)
- Interest Payments

If negative: Carried Loss (for year X+1 or X-1)

Revenue
- Operating Cost

Net Income before Allowances
- Capital Cost Allowance

Resource Profits
- Resource Allowance
- Interest Payments
- Exploration Expenditures
- Development Expenditures

Income for Earned Depletion
- Earned Depletion Allowance
- Carried Loss (from X-1 or X+1)

Income for Federal Corporate Income Tax

Federal Corporate Income Tax Otherwise Payable
- Investment Tax Credit

Net Federal Corporate Income Tax Payable

Capital Cost Allowance: applied to mine plant and machinery, the mill facility, infrastructure capital, and mine development capital after the start of commercial production. The amount allowable must be reduced by the investment tax credit (see below).

For capital expended during the development stage and for expansions of at least 25% in capacity, the deduction permitted is the greater of 15% of the allowable capital cost in the year of expenditure and 30% per year thereafter on a declining balance basis, or an amount equal to (revenue - operating cost - interest payments) from the new mine, i.e. at 100% against new mine income.

ASSUME - taxation on an individual project basis will use the 100% rate. Taxation on an integrated company basis will use the 15% and 30% rates until new mine income begins and then the balance will be deducted at the 100% rate. Note that while capital cost allowance reduces the amount of resource profits and resource allowance, a carried loss does not. Therefore, using the 15% and 30% rates until new mine income begins may be advantageous even on the individual project basis.

For other capital costs (apart from major expansion) and sustaining capital costs, the capital cost allowance is 15% of the capital cost in the year of expenditure and 30% per year thereafter on a declining balance basis for all except mine development capital costs which are allowable at 100%.

Capital expenditures incurred to control air and water pollution can be deducted at 50% per year on a straight-line basis.

Resource Allowance: 25% of resource profits.

Development Expenditures: mine development capital costs incurred before the start of commercial production are allowed to be deducted at 100%.

Earned Depletion Allowance: $1 for every $3 of allowable capital costs and expenditures up to a maximum of 25% of income for earned depletion in any year.

Allowable capital costs and expenditures include exploration expenditures; mine development, mine plant and machinery, mill facility, and infrastructure capital in the development stage; mine plant and machinery, and mill facility capital associated with a major expansion; and the processing

machinery equipment component in other capital costs (other than major expansions) and sustaining capital costs. The amount allowable must be reduced by the investment tax credit (see below).

Carried Loss: losses may be carried back three years and ahead seven years.

Federal Corporate Income Tax: 33% of income for federal tax, plus 3% surtax. Effective tax rate = 33 + 3 (.33) = 33.99%.

Investment Tax Credit: applies to mine plant and machinery, mill facility and infrastructure capital. The investment tax credit is deducted from the federal corporate income tax which would otherwise be payable to determine the net tax payable. The maximum deduction in any year is the federal corporate income tax otherwise payable.[30]

The rate of tax credit is 20% for applicable investment in the Atlantic Provinces and the Gaspe region of Quebec.

30. As a temporary measure for the period May, 1983 - December, 1988, 20% of any investment tax credits earned in excess of the federal tax otherwise payable is returnable as a cash refund.

Provincial and Territorial Corporate Income Tax

QUEBEC

Cash Flow Format:

Revenue
- Operating Cost
- Capital Cost Allowance [30% db (optional)
- Interest Payments

if negative: Carried Loss (for year X+1 or X-1)

Revenue
- Operating Cost

Net Income before Allowances
- Capital Cost Allowance

Resource Profits
- Resource Allowance
- Interest Payments
- Exploration Expenditures
- Development Expenditures

Income for Earned Depletion
- Earned Depletion Allowance
- Carried Loss (from X-1 or X+1)

Income for Quebec Corporate Income Tax

Quebec Corporate Income Tax

} same format as for Federal Corporate Income Tax

Capital Cost Allowance
Resource Allowance
Development Expenditures
Carried Loss

} Same rules as for Federal Corporate Income Tax

Earned Depletion Allowance: same rules as for federal corporate income tax except maximum annual deduction is 33 1/3% of income for earned depletion.

Quebec Corporate Income Tax: 5.5% of income for Quebec income tax.

ONTARIO

Cash Flow Format:

Revenue	same format
- Operating Cost	as for
- Capital Cost Allowance [30% db (optional)]	Federal
- Interest Payments	Corporate
if negative: Carried Loss (for year X+1 or X-1)	Income Tax

Revenue
- Operating Cost
Net Income before Allowances
- Capital Cost Allowance
- Interest Payments
- Exploration Expenditures
- Development Expenditures
Income for Percentage Depletion
- Percentage Depletion Allowance
- Carried Loss (from year X-1 or X+1)
- Income for Ontario Corporate Income Tax
Ontario Corporate Income Tax

Capital Cost Allowance	Same rules as for
Development Expenditures	Federal Corporate
Carried Loss	Income Tax

Percentage Depletion Allowance: 33 1/3% of income for percentage depletion.

Ontario Corporate Income Tax: 14.5% of income for Ontario income tax.

OTHER PROVINCES AND TERRITORIES

In British Columbia, resource allowance is not an allowable deduction in calculating income for B.C. corporate income tax. Otherwise, income for provincial and territorial corporate income tax is derived in exactly the same way as income for federal corporate income tax.

The applicable tax rates are as follows:

Alberta	11%
British Columbia	14%
Manitoba	17%
New Brunswick	15%
Newfoundland	16%
Northwest Territories	10%
Nova Scotia	15%
Saskatchewan	17%
Yukon Territory	10%

Provincial and Territorial Mining Tax

NEWFOUNDLAND[31]

Cash Flow Format:

Revenue
- Operating Cost
Net Income before Allowances
- Depreciation Allowance
- Exploration Expenditures
Income for Processing Allowance
- Processing Allowance
Income for Newfoundland Mining Tax
Newfoundland Mining Tax

Depreciation Allowance: all pre-production capital costs allowable on a straight line basis over estimated mine life. Capital expended during the productive life of a mine is allowable at 10 percent on a straight-line basis.

Processing Allowance: 8% per year of the original cost of processing assets but not to be more than 65% of the income for processing allowance.

Newfoundland Mining Tax: 20% on first 20% of income for Newfoundland mining tax; 15% on remaining income for Newfoundland mining tax.

31. The Iron Ore Company of Canada has a special tax agreement with the Newfoundland government. Their iron ore mining and processing operation in Labrador are taxed at a flat rate of 5% of taxable income. Depreciation allowance is 10% per year of all capital costs on a straight-line basis. There is no processing allowance. Interest and royalty payments are not deductible.

NOVA SCOTIA

Cash Flow Format:

Gross Metal Revenue
- Smelting, Refining, and Transportation Charges
Revenue = Net Smelter Return

Revenue
- Operating Cost
Net Income before Allowance
- Depreciation Allowance
- Exploration Expenditures
Income for Processing Allowance
- Processing Allowanc
Income for Nova Scotia Mining Tax
Nova Scotia Mining Tax

Depreciation Allowance: all capital costs except post-production mine access capital costs allowable at 100% against new mine income during the first three years of operation and at 30% per year on a straight-line basis thereafter. Post-production mine development capital costs allowable at 100%.

Processing Allowance: 8% per year of the original cost of processing assets but not to be less than 15% nor more than 65% of the income for processing allowance.

Nova Scotia Mining Tax: the greater of 2% of net smelter return or 15% of income for Nova Scotia mining tax (but subject to change by order-in-council).

NEW BRUNSWICK

Cash Flow Format:

Revenue
- Operating Cost
- Exploration Allowance
- Royalty
- Depreciation Allowance
- Interest Allowance

Income for Processing Allowance
- Processing Allowance

Income for New Brunswick Mining Tax
New Brunswick Mining Tax
- Research Credit

New Brunswick Mining Tax After Credit

Exploration Allowance: $1.50 for every $1 of exploration expenditures.

Royalty: 2% of 'net mill return' starting in the third year of mine operation.

Gross Metal Revenue
- Smelting, Refining, and Transportation Charges

Revenue
- Mill Operating Costs

Return for Processing Allowance
- Processing Allowance

Net Mill Return (i.e., value of the mill feed)

The processing allowance is determined as specified below but the amount deductible in any year cannot exceed 25% of the 'return for processing allowance'.

Depreciation Allowance: includes all capital expenditures except for exploration, research and working capital.

For capital expended during the preproduction development stage and for expansions of at least 25% in capacity, the deduction permitted is up to 100% of the allowable capital cost but not to be less than 5% per year.

Sustaining and other capital costs during the productive life of a mine are allowable at up to 33 1/3% per year on a straight-line basis with no minimum deduction.

New Brunswick (continued)

Assume maximum possible allowance is taken in each case.

Interest Allowance: 8% per year of the undepreciated cost of all assets qualifying for depreciation allowance. Note that it may in some cases be advantageous to depreciate more slowly than possible to take fuller advantage of this allowance.

Processing Allowance: annual rate applied to the original cost of processing assets but not to be less than 15 percent nor more than 65 percent of income for processing allowance.
8% of concentrator assets.
15% of smelting and refining assets.

New Brunswick Mining Tax:

income for mining tax	marginal rate
up to 100,000	exempt
100,000 and over	16%

Research Credit: 25% of research expenditures.

QUEBEC

Cash Flow Format:

Revenue
- Operating Cost

if negative: Carried Loss

Revenue
- Operating Cost
- Depreciation Allowance
- Exploration Expenditures

Income for Exploration and Investment Allowance
- Exploration and Investment Allowance

Income for Processing Allowance
- Processing Allowance

Income for Quebec Mining Tax
Quebec Mining Tax Otherwise Payable
- Carried Credit for Unused Exemption
- Deduction for Carried Loss

Net Quebec Mining Tax Payable
Refundable Credit

Quebec (continued)

Depreciation Allowance: mine development capital costs at 100% per year; all other capital costs at 30% per year on a straight-line basis.

Exploration and Investment Allowance: $1 for every $3 of pre-production exploration expenditures, capital costs of processing facilities, and exploration costs incurred at operating underground mines,[32] up to a maximum of 33 1/3% of income for exploration and investment allowance in any year.

Processing Allowance: annual rate applied to the original cost of processing assets but not to be less than 15% nor more than 65% of income for processing allowance.

8% [illegible]e concentrated

15% if concentrate is smelted and/or refined in Quebec

Rate applies to all processing assets up to and including final stage.

The 15% rate applies to gold mill assets if the facility includes a smelter which produces dore or impure bullion.

Quebec Mining Tax Otherwise Payable:

income for mining tax	marginal rate
up to 500,000	exempt
500,000 and over	18%

At the 18 percent tax rate, the $500,000 exemption is equivalent to a credit of $90,000. Any part of the credit which is not used during a given year may be carried forward three years.

Deduction for Carried Loss: 18% of 'carried loss' in the year following the loss. This deduction can be carried back three years and ahead seven years.

Refundable Credit

18 percent of the loss resulting from exploration expenditures and depreciation allowance during a given year, up to the limit of 18 percent of the loss incurred during the year.

Revenue
- Operating Cost
- Depreciation Allowance
- Exploration Expenditures

if negative; Loss Incurred During Year

32. Actually limited to a prescribed list of exploration expenditures which are a function of such factors as depth of exploration and distance from mine workings.

ONTARIO

Cash Flow Format:

Revenue
- Operating Cost
Net Income before Allowances
- Depreciation Allowance
- Exploration Expenditures
Income for Processing Allowance
- Processing Allowance
Income for Ontario Mining Tax
Ontario Mining Tax

Depreciation Allowance: mine development capital costs at 100% per year; mine plant and equipment at 30% per year on a straight-line basis; mill, infrastructure and all other capital costs at 15% per year on a straight-line basis.

Processing Allowance: annual rate applied to the original cost of processing assets but not to be less than 15% nor more than 65% of income for processing allowance.

8% if ore concentrated
12% if ore smelted in Canada
16% if ore refined in Canada
20% if ore refined or fabricated in northern Ontario

Rate applies to all processing assets up to and including final stage.

The 12% rate applies to gold mill assets if the facility includes a smelter which produces dore or impure bullion.

Ontario Mining Tax:

income for mining tax	marginal rate
up to 500,000	exempt
500,000 and over	20%

MANITOBA

Cash Flow Format:

Revenue
- Operating Cost
Net Income before Allowances
- Depreciation Allowance
- Exploration Expenditures
Income for Processing Allowance
- Processing Allowance
Income for Manitoba Mining Tax
Manitoba Mining Tax Otherwise Payable
Investment Tax Credit
Net Manitoba Mining Tax Payable

Depreciation Allowance: all capital costs at 20% per year on a declining-balance basis. The amount allowable must be reduced by the investment tax credit (see below).

Processing Allowance: average of 8% per year of the original cost of processing assets* but not to be less than 15% nor more than 65% of income for processing allowance.

Manitoba Mining Tax: 18% of income for Manitoba mining tax.

Investment Tax Credit: 5 percent of capital expenditures on mine development, mine plant and machinery, and processing assets, which have been made for the purposes of bringing a new mine into production, carrying out a major expansion, or 'modernizing' existing facilities to increase production potential.

Allowable capital costs for 'depreciation allowances' must be reduced by the amount of the investment tax credit.

The investment tax credit may be deducted in the year a qualified asset is acquired and can be carried forward for another five years.

* The May 1979 Manitoba budget increased the processing allowance rate from 8 percent to 10 percent per year but restricted the definition of processing assets to exclude common service facilities. Thus, assume 8 percent as an average rate on all processing assets.

SASKATCHEWAN (metallic minerals excluding uranium)

Cash Flow Format:

Revenue
- Operating Cost
Net Income before Allowances
- Depreciation Allowance
- Exploration Expenditures
Income for Processing Allowance
- Processing Allowance
Income for Saskatchewan Mining Tax
Saskatchewan Mining Tax

Depreciation Allowance: mine development expenditures and mine plant and machinery capital costs allowable at 100%. Capital costs of processing, housing, and townsite facilities allowable at 30% per year on a declining-balance basis. For capital expenditures for road and power facilities, assume half is written off at 100%, and the other half at 30% per year declining balance. Assume 70% of infrastructure capital expenditures is deducted at 30% per year declining balance, and the remaining 30% of the infrastructure at 100%.

Processing Allowance: 8% per year of the original cost of processing assets but not to be less than 20% nor more than 65% of the income for processing allowance for copper-zinc deposits, and not to be less than 15% or more than 65% of income for other deposits.

Saskatchewan Mining Tax: 12.5% of income for Saskatchewan mining tax.

ALBERTA (metallic minerals)

Payout: date on which the cumulative gross revenue of the mine equals the sum of cumulative allowed capital costs, cumulative operating costs, cumulative on-site exploration and development costs, cumulative annual capital allowance, and cumulative pre-payout royalty.

Allowed Capital Costs: includes all capital expenditures directly attributable to the mine except for exploration expenditures, development costs, and working capital. Included in this category is an allowance for indirect capital costs of 1% of the capital costs incurred.

ALBERTA (continued)

Operating Costs: includes smelting, refining, and transportation charges, and all other operating costs directly attributable to the mine.

Annual Capital Allowance: 15% of the unrecovered allowed capital costs in a year. Where the period to which the allowance applies is less than a full year, the allowance must be reduced to reflect the eligible period of the year.

Cash Flow Format: applies before payout is achieved, and defines mine mouth revenue after payout occurs.

Gross Revenue
- Smelting, Refining and Transportation Charges
- Mill Operating Costs
- Annual Capital Allowance on Processing Capital Expenditures

Mine Mouth Revenue

Alberta Pre-Payout Royalty: 1% of mine mouth revenue.

Cash Flow Format for Post-Payout Royalty: applies after payout occurs.

Gross Revenue
- Allowed Capital Costs
- Operating Costs
- On-Site Exploration and Development Costs

Revenue for Processing Allowance
- Processing Allowance
- Operating Losses from Prior Years
- Off-Site Exploration Costs

if negative, Carried Loss for Next Year
if positive, Net Revenue

Allowed Capital Costs: permits 100% write down of allowed capital expenditures in the year of acquisition. Included in this category is an allowance for indirect capital costs of 1% of the capital costs incurred.

Processing Allowance: 10% per year of the original cost of processing assets but not to be more than 65% of the revenue for processing allowance.

Operating Losses: may be carried forward until recovered. The calculation of an operating loss excludes royalty paid.

Off-Site Exploration Costs: incurred in Alberta before the commencement of mining operations.

Alberta Post-Payout Royalty: the greater of 1% of mine mouth revenue or 12% of net revenue.

BRITISH COLUMBIA

Cash Flow Format:

Revenue
- Operating Cost
Net Income before Allowances
- Depreciation Allowance
- Interest Payments
- Exploration Expenditures
Income for Earned Depletion Allowance
- Earned Depletion Allowance
Income for Processing Allowance
- Processing Allowance
Income for British Columbia Mining Tax
British Columbia Mining Tax

Depreciation Allowance: applies to all capital costs. Calculated in the same manner as explained under 'capital cost allowance' and 'development expenditures' for federal corporate income tax.

Earned Depletion Allowance: calculated in the same manner as explained for federal corporate income tax.

Processing Allowance: 8% per year of the original cost of processing assets but not to be less than 15% nor more than 50% of income for processing allowance.

British Columbia Mining Tax: 17.5% of income for mining tax.

Note: all allowances must be taken on an individual project basis.

NORTHWEST TERRITORIES

Cash Flow Format:

Revenue
- Operating Cost
Net Income before Allowances
- Depreciation Allowance
- Exploration Expenditures
Income for Processing Allowance
- Processing Allowance
Income for Northwest Territories Mining Tax
Northwest Territories Mining Tax

Depreciation Allowance: all capital costs except post-production mine development capital costs allowable at 15% per year on a straight-line basis; post-production mine development capital costs at 100%.

Processing Allowance: 8% per year of the original cost of processing assets but not to be less than 15% nor more than 65% of the income for processing allowance.

Northwest Territories Mining Tax:

income for mining tax	marginal rate
up to 10,000	exempt
10,000 - 1 million	3%
1 million - 5 million	5%
5 million - 10 million	6%
10 million and over	+ 1% for each additional $5 million up to 12% maximum

YUKON TERRITORY

Cash Flow Format:

Revenue
- Operating Cost
Net Income before Allowances
- Depreciation Allowance
- Exploration Expenditures
Income for Yukon Mining Tax
Yukon Mining Tax

Depreciation Allowance: all capital costs except post-production mine development capital costs allowable at 15% per year on a straight-line basis; post-production mine development capital costs at 100%.

Yukon Mining Tax:

income for mining tax	marginal rate
up to 10,000	exempt
10,000 - 1 million	3%
1 million to 10 million	5%
5 million - 10 million	6%
10 million and over	+ 1% for each additional $5 million up to 12% maximum

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